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Geotechnical and Structures Laboratory

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Engineer Research and Development Center

Laboratory and Field Evaluation of Dust Abatement Products for Expedient Helipads

Lulu Edwards, Jeb S. Tingle, and Quint Mason

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Abstract: The U.S. Army Engineer Research and Development Center (ERDC) was tasked by the U.S. Marine Corps Systems Command (USMC) to evaluate commercial dust palliatives that have become available since the comprehensive testing performed on helipads by the ERDC in 2005. Both laboratory and field evaluations were performed on the dust palliatives. Laboratory evaluations consisted of observing erosion measurements and optical dust concentration for three product application concentrations, 0.4, 0.8, and 1.2 gsy (gallons/square yard). Field evaluation consisted of constructing 150-ft by 150-ft helipads at Marine Corps Air Station, Yuma, AZ. Evaluation of the dust palliatives was based on their ability to prevent dust and foreign object debris as well as their compatibility with existing USMC dust abatement equipment. Approved products will be used to update the USMC *Dust Abatement Handbook* (PCN 50011240000).

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Preface

The purpose of this report is to present results of laboratory and field evaluations of commercial dust abatement products that are new to the market since the comprehensive testing performed by the U.S. Army Engineer Research and Development Center (ERDC) in 2004 and 2005. Projected users of this report include military personnel who plan and/or construct expedient helipads.

This report was prepared by personnel of the ERDC Geotechnical and Structures Laboratory (GSL), Vicksburg, MS. The findings and recommendations presented herein are based upon laboratory tests conducted at Vicksburg, MS, from July to September 2009 and field tests conducted at the Marine Corps Air Station (MCAS), Yuma, AZ, during April 2010. The principal investigators for this project were Lulu Edwards and Jeb S. Tingle of the GSL. Laboratory work was performed by Lulu Edwards and Afton Wilson. Fieldwork was performed by Lulu Edwards, Jeb Tingle, Quint Mason, Chase Bradley, and Jim Cole of the GSL Airfield and Pavements Branch (APB); Stacy Washington and Leroy Hardin of the ERDC Directorate of Public Works; and Richard Read, Army Corps of Engineers-Information Technology.

This report was prepared by Lulu Edwards, Jeb S. Tingle, and Quint Mason. The testing and analyses were conducted under the supervision of Dr. Gary L. Anderton, Chief, APB; Dr. Larry N. Lynch, Chief, Engineering Systems and Materials Division; Dr. William P. Grogan, Deputy Director, GSL, and Dr. David W. Pittman, Director, GSL.

COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. Jeffery P. Holland was Director.

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412	cubic decimeters (liters)
inches	0.0254	meters
miles per hour	0.44704	meters per second
pounds (mass)	0.45359237	kilograms
quarts (U.S. liquid)	9.463529 E-04	cubic meters
square yards	0.8361274	square meters
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

During 2004–2005, the U.S. Army Engineer Research and Development Center (ERDC) developed comprehensive guidance for reducing the amount of dust on roads, helipads, and airfields (Rushing and Tingle 2006). However, new commercial products have been developed since the original testing. The U.S. Marine Corps Systems Command (MCSC) tasked the ERDC with evaluating emerging technologies for liquid dust control solutions for helipads, roads, and base camps. This project consisted of testing new commercial dust palliatives under realistic operating conditions to assess their effectiveness in mitigating dust and to determine their compatibility with existing USMC dust abatement equipment.

Objective

The objective of this study was to evaluate new dust palliatives currently on the market. This report provides information for the following:

a. Testing procedures and data from the laboratory evaluation of products to determine application rates and curing behavior.

b. Testing procedures and data from the field evaluation of the dust palliatives.

c. Comparison of laboratory and field evaluations.

Scope

Laboratory and field tests were conducted on commercially available dust palliatives. The laboratory component of this project was used to evaluate the performance of different products under simulated helipad conditions. Data from the laboratory testing were used to determine the most effective concentration levels as well as to screen the products for the field tests. Thirteen products were evaluated in the laboratory; ten of these had not previously been evaluated by ERDC. The laboratory evaluation of the dust palliatives was conducted from 28 Jul–23 Sep 2009 at the ERDC, in Vicksburg, MS.

The field evaluation was conducted 8–17 April 2010 at the Auxiliary II site of the Marine Corps Air Station (MCAS) in Yuma, AZ. Thirteen helipads were constructed for field testing; twelve were treated with various palliatives, and one was left untreated. Twelve helipads, including the untreated helipad, were evaluated under live flight testing of UH-1, CH-46, and CH-53 helicopters. One of the treated helipads was constructed as an extra helipad to evaluate the penetration depth but was not evaluated under live flight testing due to time constraints.

Results from both the laboratory and field testing are presented in this report. Chapter 2 details the properties of dust palliatives. Chapter 3 describes the laboratory testing and reports the test results. Chapter 4 summarizes the construction of the helipads and presents the results of the field testing. Chapter 5 states the conclusions and recommendations for expeditionary helipad dust abatement.

2 Properties of Dust Palliatives

All dust palliatives tested are commercially available and can be purchased in quantities ranging from 1 L to 20,000 gal. The most common method of shipping is the tote, which ranges from 264 gal (1000 L) to 275 gal. The costs of the products at the time of testing ranged from $0.65/gal to $13.80/gal. Dust palliatives are applied in different concentrations. Some are applied neat, which means they are applied as received, straight from the container. Some are diluted with water; the dilution ratio varies depending on the product.

The dust palliatives used in this exercise can be divided into two categories according to the type of crust that is formed with their use, hard or soft. There are advantages and disadvantages to both types of crusts. A hard crust is more stable, but the product must be applied so that there is sufficient penetration to prevent punctures of the crust during landings; otherwise, dangerous foreign object debris (FOD) may result. A soft crust does not create FOD but may not be as durable over time.

Hard-crust palliatives

Hard-crust palliatives cause soil particles to form brittle physical bonds. They are generally polymer-based solutions with surfactants and normally have to be diluted with water. Once they are applied, the polymer particles begin to coalesce as the water evaporates from the system, leaving a soil-polymer matrix that prevents small dust particles from escaping the surface. The crust layer formed is very defined and hard. The following paragraphs describe the hard-crust palliatives investigated in this study.

TerraLOC®

TerraLOC ® is a polyvinyl alcohol solution made by MonoSol, LLC. TerraLOC® is water soluble and forms a film/matrix on soil. TerraLOC® comes in different concentrations that may or may not require dilution. Two concentrations were tested at ERDC: TerraLOC® 16 and TerraLOC® HLZ (also known as TerraLOC® 12). TerraLOC® 16 required three parts water to one part product. TerraLOC® HLZ was applied neat. According to the manufacturer, the recommended storage temperature is from 50°F to 100°F, and the recommended application temperature is greater than

70°F. The recommended curing time is from 3 to 20 hr. The manufacturer says the product can be reactivated with the addition of water. After application, the product is expected to last up to 4 months.

Biotrol

Biotrol is a blend of glycerin and polymer made by Midwest Industrial Supply, Inc. Biotrol is diluted by adding two parts water to one part product. According to the manufacturer, the recommended storage temperature is from 20°F to 100°F, and the recommended application temperature is greater than 30°F. No curing time is required for this product. According to the manufacturer, the product is expected to last up to a year, depending on the application rate. Biotrol actually forms a semi-hard crust that is expected to crumble upon very light pressure.

Soiltac®

Soiltac® is a liquid copolymer emulsion product made by Soilworks®, LLC. Soiltac® requires a dilution of 3 parts water to 1 part product. According to the manufacturer, the recommended storage temperature and application temperature are both greater than 32°F. The recommended curing time is approximately 24 hr. After a topical application, the product is expected to last up to 2 years. Soiltac® was tested during the previous round of field testing (Rushing et al. 2006).

Powdered Soiltac®

Powdered Soiltac® is a dispersible copolymer product made by Soilworks®, LLC. Powdered Soiltac® must be mixed with water to form the solution (0.86 lb product to 1 gal water). According to the manufacturer, the recommended storage temperature is less than 212°F, and the recommended application temperature is greater than 32°F. The recommended curing time is approximately 24 hr. After a topical application, the product is expected to last up to 2 years. Powdered Soiltac® was tested during the previous round of field testing (Rushing et al. 2006).

Soft-crust palliatives

The following paragraphs describe the soft-crust palliatives investigated.

Enviroseal Dust Control™

Enviroseal Dust Control (EDC™) is a synthesized blend of organic vegetable oils and surfactants made by Enviroseal Company LLC. According to the manufacturer, the recommended storage and application temperature range is 0°F to 140°F. The product is applied neat (undiluted). After application, the product is expected to last 6 to 12 months. Enviroseal Company LLC also manufactures a product, currently named EDC2, that is similar to the original EDC™ but that can be applied at a wider range of temperatures, from -10°F to 150°F.

Road Dust Suppressant

Road Dust Suppressant (RDS) is a canola oil-based product developed by Milligan's Bio-Tech. According to the manufacturer, the recommended storage temperature is -40°F to 104°F, and the recommended application temperature is greater than 50°F. A cure time of at least 24 to 36 hr is recommended. It is applied neat (undiluted).

Newtrol™

Newtrol™ is a blend of glycerin and polymer made by Midwest Industrial Supply, Inc. Newtrol™ is applied neat (undiluted). According to the manufacturer, the recommended storage temperature range is 20°F to 100°F, and the recommended application temperature is greater than 30°F. No curing time is required for this product. After application, the product is expected to last up to a year, depending on the application rate.

EK35B

EK35B is a blend of synthetic isoalkane and binders made by Midwest Industrial Supply, Inc. EK35B is applied neat (undiluted). According to the manufacturer, the recommended storage temperature is from -50°F to 150°F, and the recommended application temperature is greater than 40°F. No curing time is required for this product. After application, the product is expected to last up to 1 year, depending on the application rate.

Dustaway®

Dustaway® is a vegetable oil-based glycerin/glycerol product made by Soilworks®, LLC. Dustaway® requires a dilution of 3 parts water to 1 part product. According to the manufacturer, the recommended storage temperature is less than 320°F, and the recommended application temperature is greater than -27°F. No curing time is required for this product. After application, the product is expected to last up to 6 months.

Durasoil®

Durasoil® is a synthetic organic fluid made by Soilworks®, LLC. Durasoil® is applied neat (undiluted). According to the manufacturer, the recommended storage temperature is less than 300°F, and the recommended application temperature is greater than 5°F. No curing time is required for this product. After application, the product is expected to last up to 16 months. Durasoil® was tested during the previous round of field testing (Rushing et al. 2006).

3 Laboratory Testing of Dust Palliatives

Each palliative was evaluated in the laboratory to verify the manufacturer's recommended application rates. The test method used in this study was developed during previous dust abatement evaluations at ERDC and refined during the last round of testing, which occurred from June 2005 to February 2006. A complete description of the testing apparatus, protocols, and history can be found in previous testing reports (Tingle et al. 2004; Rushing et al. 2007).

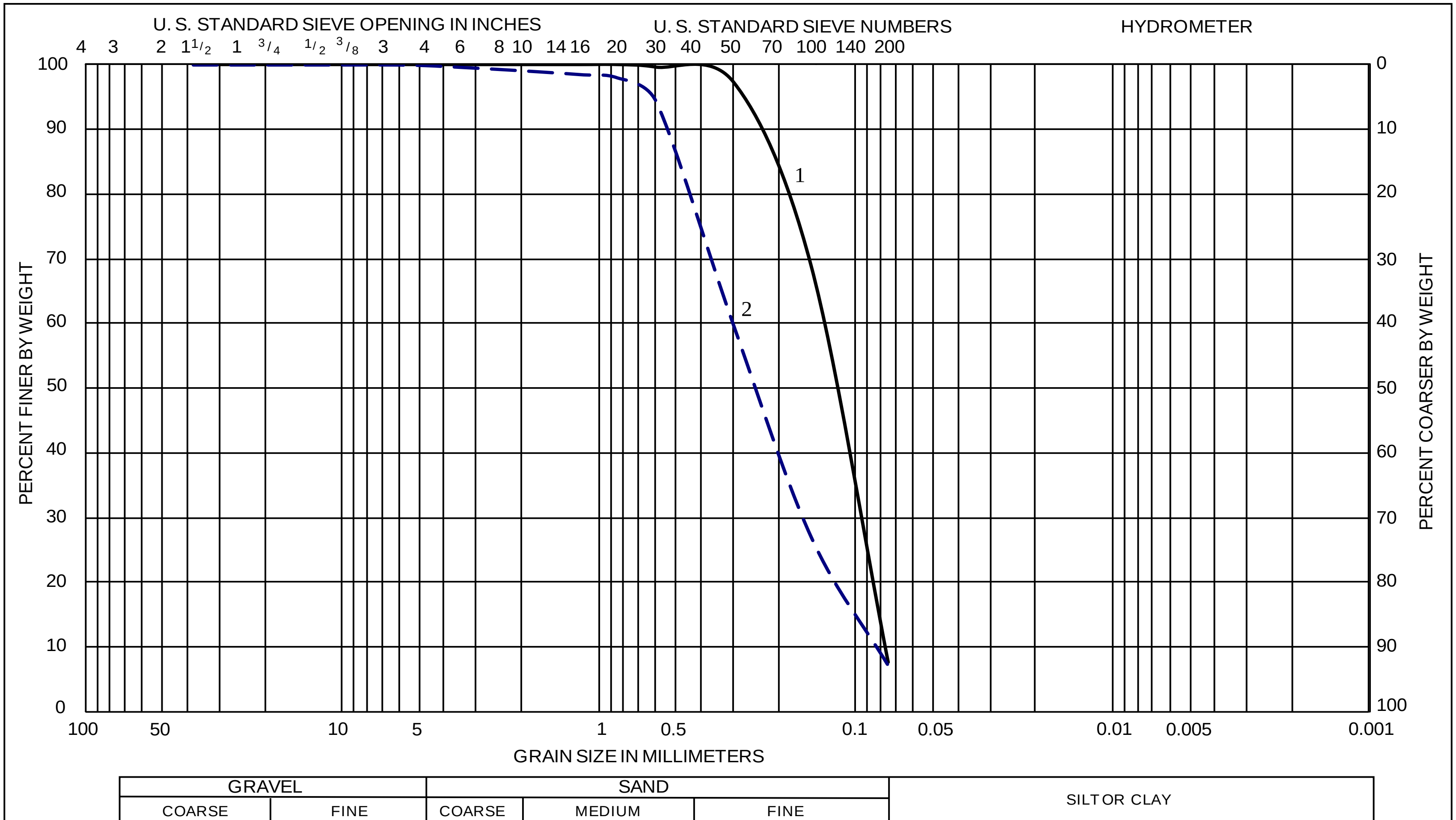
Specimen preparation

Test specimens were prepared in 6-in. by 6-in. by 2-in. deep square molds. The soil used for the test came from Yuma, AZ. The grain size distribution curve for the soil is given in Figure 1. The soil was classified as poorly graded sand, SP, according to the Unified Soil Classification System (ASTM 1998). The native material was processed prior to testing by putting it into an oven to remove all moisture and then shaking it over a No. 16 sieve to remove any large soil grains.

Dust palliative application

All specimens were sprayed with a topical application of the dust palliative at application rates of 0.4, 0.8, or 1.2 gallons per square yard (gsy) in a manner similar to field application. Three specimens were tested for each application rate in the product application device (Figure 2).

The specimens were placed into a plastic tote in order to collect overspray. The dust palliative was diluted and mixed, as applicable, and poured into an aluminum canister. The canister was equipped with a ball valve and plastic wide-fan spray nozzle on the bottom. The top of the canister had a port for attaching an air hose to pressurize the canister and achieve the necessary fan width from the spray nozzle (Figure 3). This system required calibration for each product because higher viscosity liquids required greater pressures to obtain equal flow rates. The canister was mounted onto a carriage attached to a motorized transfer mechanism. A rack and pinion system powered by a variable-speed DC motor was used to achieve uniform displacement rates. A rheostat and dial gage were used to adjust



SAMPLE NO.	MATERIAL	CLASSIFICATION	NAT W%	LL	PL	PI
1	Laboratory Sand	Poorly Graded Silty Sand (SP-SM)			NP	
2	Field Sand	Poorly Graded Silty Sand (SP-SM)			NP	

GRADATION CURVES	
PROJECT	**Dust Abatement**
SOURCE	Yuma, AZ
DATE	2010

Figure 1. Gradation curve for Yuma sand (SP-SM).

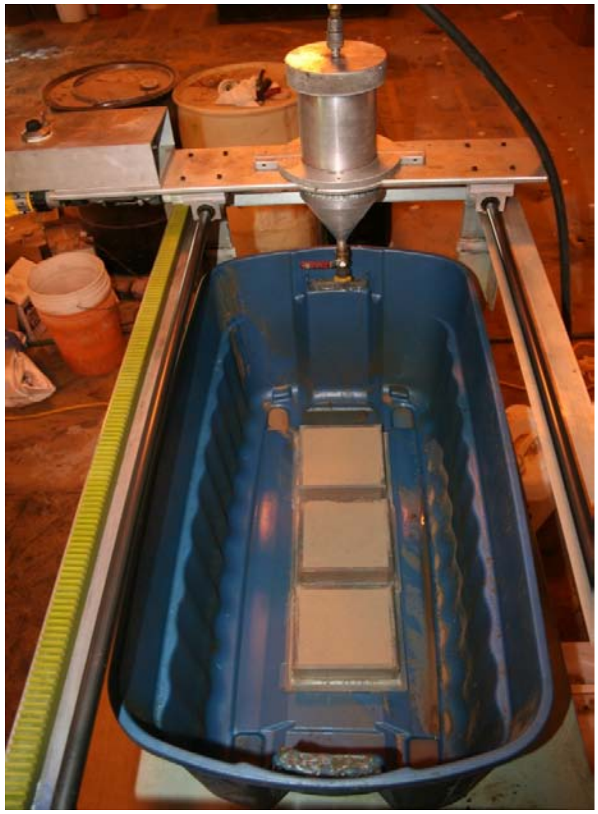


Figure 2. Dust palliative application device.

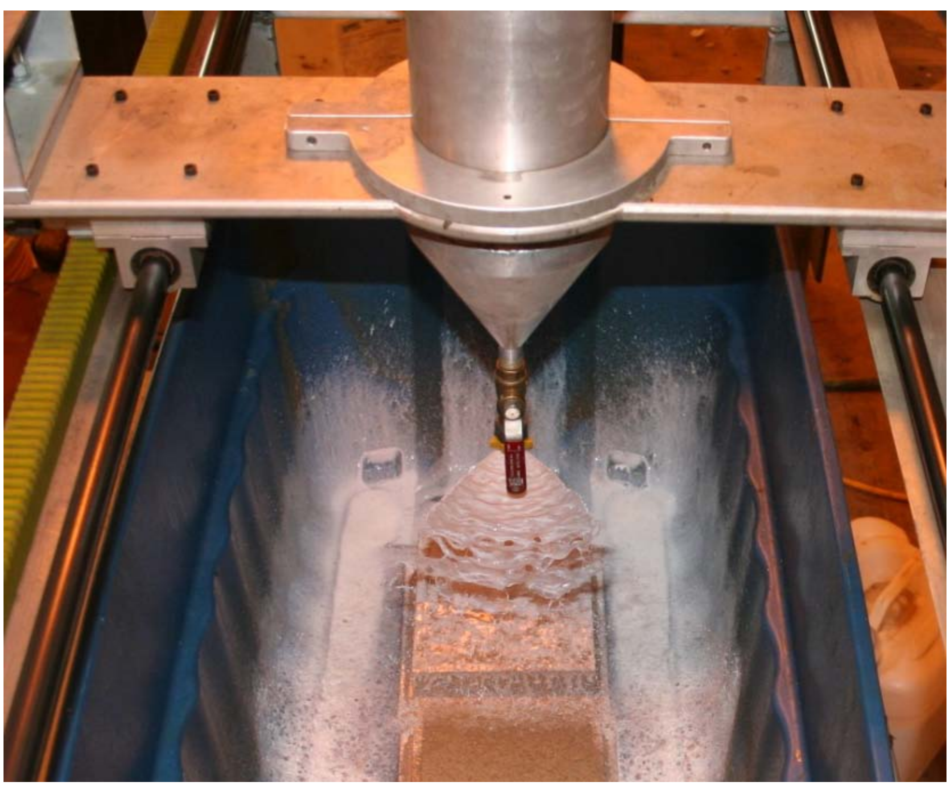


Figure 3. Dust palliative is sprayed evenly onto specimens via the spray nozzle.

travel speeds and calibration to achieve the desired application rates based on both speed and volumetric output.

Curing mechanism

Specimens were placed under infrared lamps and adjusted to produce surface temperatures of 120°F for curing (Figure 4). Specimens were tested after 24 hr of curing time. The curing simulation approximates conditions that products would experience during field testing.

Figure 4. Curing device consisting of infrared lamps adjusted to produce surface temperatures of 120°F.

Air impingement testing

Specimens were tested in a chamber designed to simulate wind velocities encountered near aircraft. The testing chamber was 4 ft long, 1 ft wide, and 2 ft tall (Figure 5). The chamber was sealed from external air to prevent dust from escaping during testing. Air velocities of 150 mph were generated by an electric fan motor and transmitted through a 3-in. polyvinyl chloride pipe with a rectangular aperture 4.5 in. wide and 0.5 in. tall (Figure 6). A return air duct circulated air from the testing chamber to the electric fan to equilibrate pressure. Air blasts were initiated 1 in. above the specimen at an angle of 20° from horizontal and lasted for 30 sec. Additionally, during the air impingement test, 300 g of 20–30 grade Ottawa sand was injected into the air stream. The sand injection increased surface scour and was intended to simulate conditions during aircraft landing as displaced particles impart additional abrasion to the ground surface. The Ottawa sand provided uniform testing, consistent with the previous testing, for comparison purposes.

Figure 5. Air impingement testing chamber.

Figure 6. Inside view of the air impingement chamber.

Evaluation methods

Erosion potential

Specimens were evaluated on their ability to resist surface erosion during the testing sequence. Quantification of soil loss under this test method was achieved by weighing specimens before and after they were subjected to the air impingement test. The amount of soil displaced from the specimen was considered an indication of how well the product would perform. Dust palliatives that prevented surface erosion were expected to perform well in field conditions. Products with little resistance to wind erosion would disintegrate rapidly during the test. This method was used to determine the relative effectiveness of dust palliatives and to identify quantities of palliative necessary to provide acceptable levels of dust mitigation. All of the specimens were compared to soil sprayed with only water as a baseline.

Erosion potential data indicating the mass lost during air impingement testing are listed in Table 1 and shown graphically in Figure 7. Data presented here are the average and standard deviation of the mass lost for the three specimens for each concentration tested. Photographs of the specimens after the application of dust palliatives and also after air impingement testing are located in Appendix A.

Table 1. Results of air impingement testing in terms of erosion potential, or mass loss.

	Erosion Potential, Average Mass Loss (grams) [1]					
Product	0.4 gsy Average	0.4 gsy Standard Deviation	0.8 gsy Average	0.8 gsy Standard Deviation	1.2 gsy Average	1.2 gsy Standard Deviation
Water	1537.3	42.7	1492.7	15.0	1514.3	93.4
TerraLOC® 16	212.7	34.2	78.7	44.0	5.0	5.0
TerraLOC® HLZ	322.0	82.7	69.3	20.0	24.0	28.8
EDC™	3.3	5.8	22.7	37.5	78.7	29.1
RDS	4.0	5.3	38.0	36.4	124.0	57.2
Biotrol	20.0	2.0	5.3	7.6	16.7	8.3
Newtrol™	552.7	410.6	44.7	5.0	32.7	6.1
EK35B	28.7	8.1	28.7	3.1	22.0	4.0
Dustaway®	1251.3	170.2	12.0	5.3	16.7	27.2
Durasoil®	1023.0	193.7	639.3	135.4	264.7	111.7
Soiltac®	86.7	4.6	24.7	15.1	0.7	1.2
Powdered Soiltac®	74.0	112.6	18.7	12.2	0.0	0.0
EDC2	21.3	18.6	0.0	0.0	16.0	21.2

[1] Average mass loss is the average of the three specimens tested per concentration.

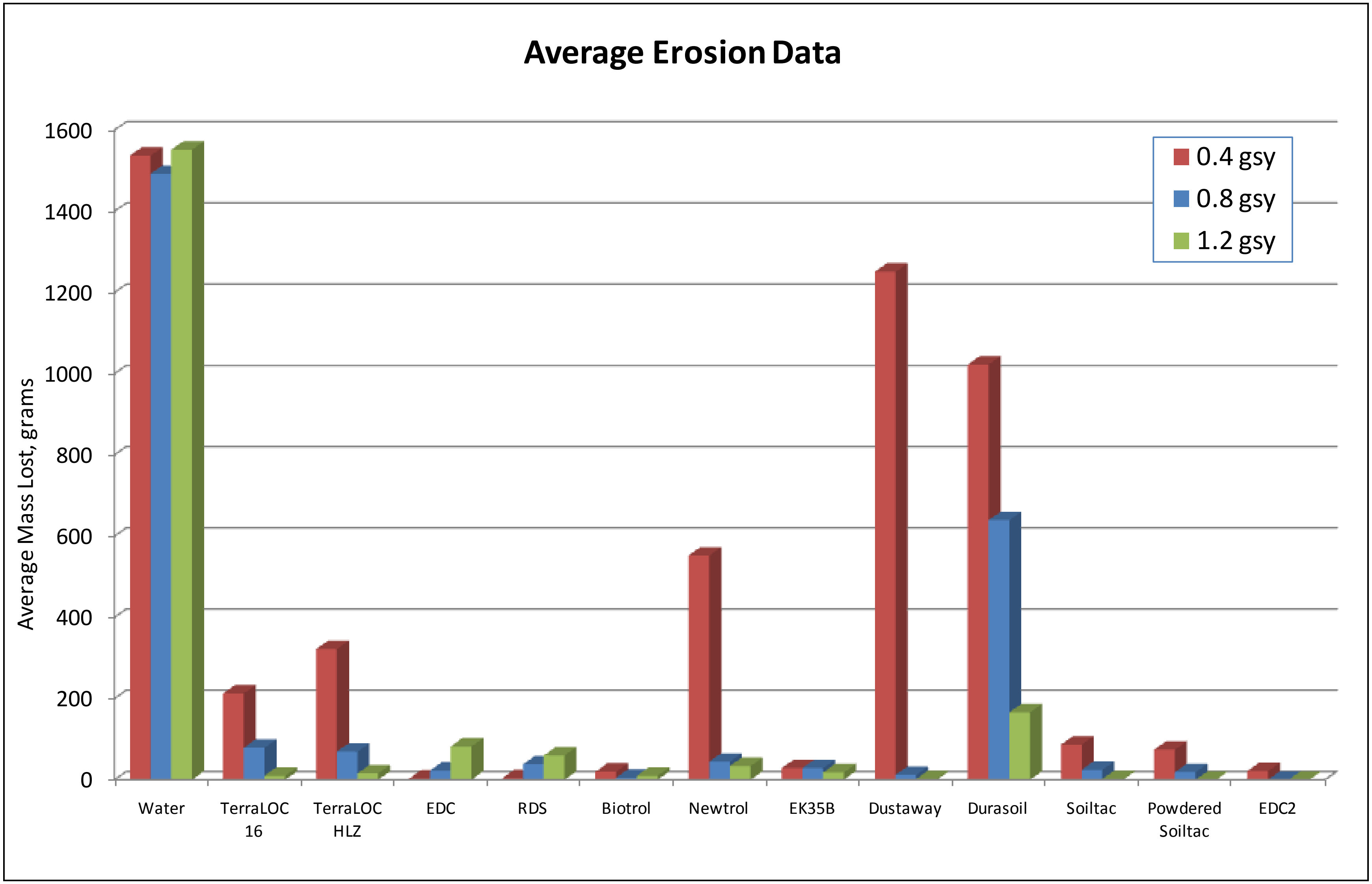


Figure 7. Air impingement results in terms of mass lost during testing.

Optical dust concentration measurements

Dust concentrations within the testing chamber were recorded using a HAZDUST III personal dust monitor. The HAZDUST III uses optical techniques to record dust concentrations in the air. The monitor can detect dust particles from 0 to 100 microns in size at concentrations up to 200 mg/m^3. Measurements were recorded at 1-sec intervals and stored on the dust monitor's internal computer. Data were collected during the 30 sec of air impingement and 120 sec subsequent to the air impingement to observe the rate of settling of dust within the testing chamber.

Dust concentration data for the dust palliatives tested are given in Table 2 and shown graphically in Figure 8. The dust concentration data presented here are the average of the maximum values obtained by the sensor during testing of three specimens, normalized by subtracting the initial concentration.

Table 2. Results of air impingement testing in terms of optical concentration.

Product	Average Optical Concentration (mg/m^3) [1]					
	0.4 gsy Average	0.4 gsy Standard Deviation	0.8 gsy Average	0.8 gsy Standard Deviation	1.2 gsy Average	1.2 gsy Standard Deviation
Water	174.4	3.5	173.4	1.8	172.2	1.7
TerraLOC® 16	45.5	4.6	31.7	8.9	19.6	3.0
TerraLOC® HLZ	17.6	2.0	9.2	1.3	6.6	2.9
EDC™	10.8	3.5	10.3	4.8	7.9	1.0
RDS	10.9	7.8	7.1	2.2	7.3	0.8
Biotrol	16.0	3.5	13.6	2.9	12.4	4.0
Newtrol™	40.8	28.1	62.4	77.2	9.3	8.6
EK35B	6.6	2.3	5.0	4.1	5.7	6.8
Dustaway®	73.2	3.1	1.9	1.1	2.0	2.7
Durasoil®	38.9	21.8	32.6	7.1	21.7	3.5
Soiltac®	69.5	21.4	38.0	6.7	15.5	3.7
Powdered Soiltac®	40.9	31.7	20.1	4.0	21.6	5.0
EDC2	9.0	6.4	10.8	0.6	5.3	4.0

[1] Average optical concentration is the average of the three specimens tested per concentration.

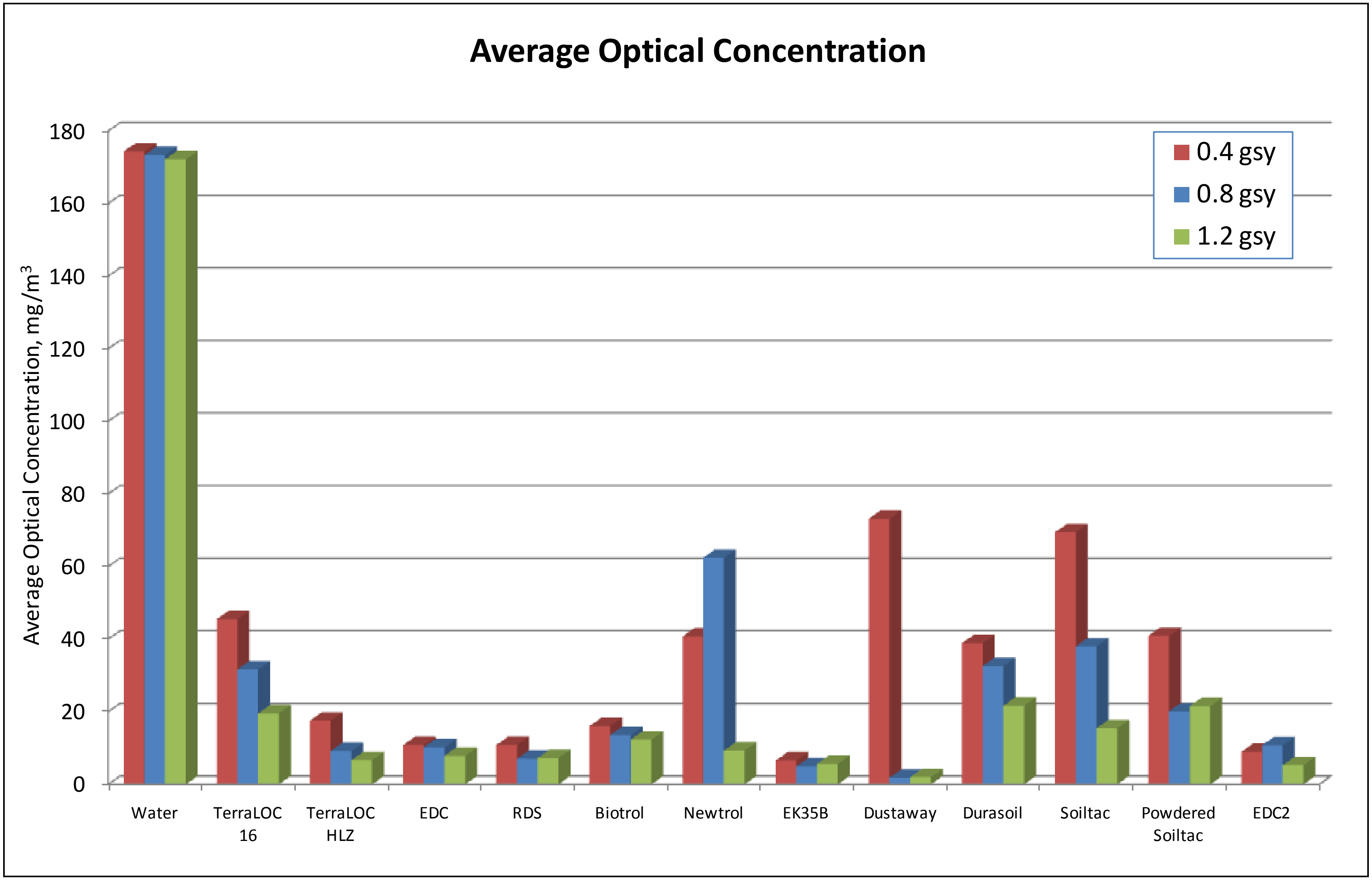


Figure 8. Air impingement results in terms of optical concentration during testing.

Penetration depth

The previous two dust abatement studies indicated that penetration depth can be a crucial indicator of performance. In Rushing et al. (2006), a penetration depth of at least 1 in. was recommended for polymer emulsion products to minimize FOD potential.

For each specimen tested, the maximum penetration depth was recorded. The average of the maximum penetration depth for the three specimens is given in Table 3 and shown graphically in Figure 9. Photographs of the specimens after the penetration depth measurements are located in Appendix A. These photographs depict the type of crust each product forms and the behavior of the crust after being broken. Some of the palliatives form hard crusts that are difficult to break up, although they form large pieces when they do break. Other palliatives form soft crusts that crumble easily under light pressure during the measurement process.

Table 3. Crust thickness or penetration depth.

	Average Crust Thickness (in.) [1]					
Product	0.4 gsy Average	0.4 gsy Standard Deviation	0.8 gsy Average	0.8 gsy Standard Deviation	1.2 gsy Average	1.2 gsy Standard Deviation
Water	n/a	n/a	n/a	n/a	n/a	n/a
TerraLOC® 16	0.48	0.03	0.76	0.12	0.84	0.11
TerraLOC® HLZ	0.30	0.04	0.47	0.03	0.44	0.02
EDC™	0.76	0.05	0.71	0.12	0.79	0.04
RDS	0.75	0.01	0.72	0.10	0.61	0.10
Biotrol	0.56	0.17	1.02	0.13	1.12	0.12
Newtrol™	0.65	0.24	0.77	0.08	1.08	0.25
EK35B	0.77	0.06	0.89	0.09	0.77	0.09
Dustaway®	0.00	0.00	0.34	0.06	0.52	0.03
Durasoil®	0.84	0.08	0.85	0.07	0.81	0.31
Soiltac®	0.54	0.02	0.47	0.07	0.54	0.12
Powdered Soiltac®	0.41	0.02	0.51	0.04	0.69	0.09
EDC2	0.54	0.06	0.49	0.18	0.65	0.04

[1] Average crust thickness is the average of the three specimens tested per concentration.

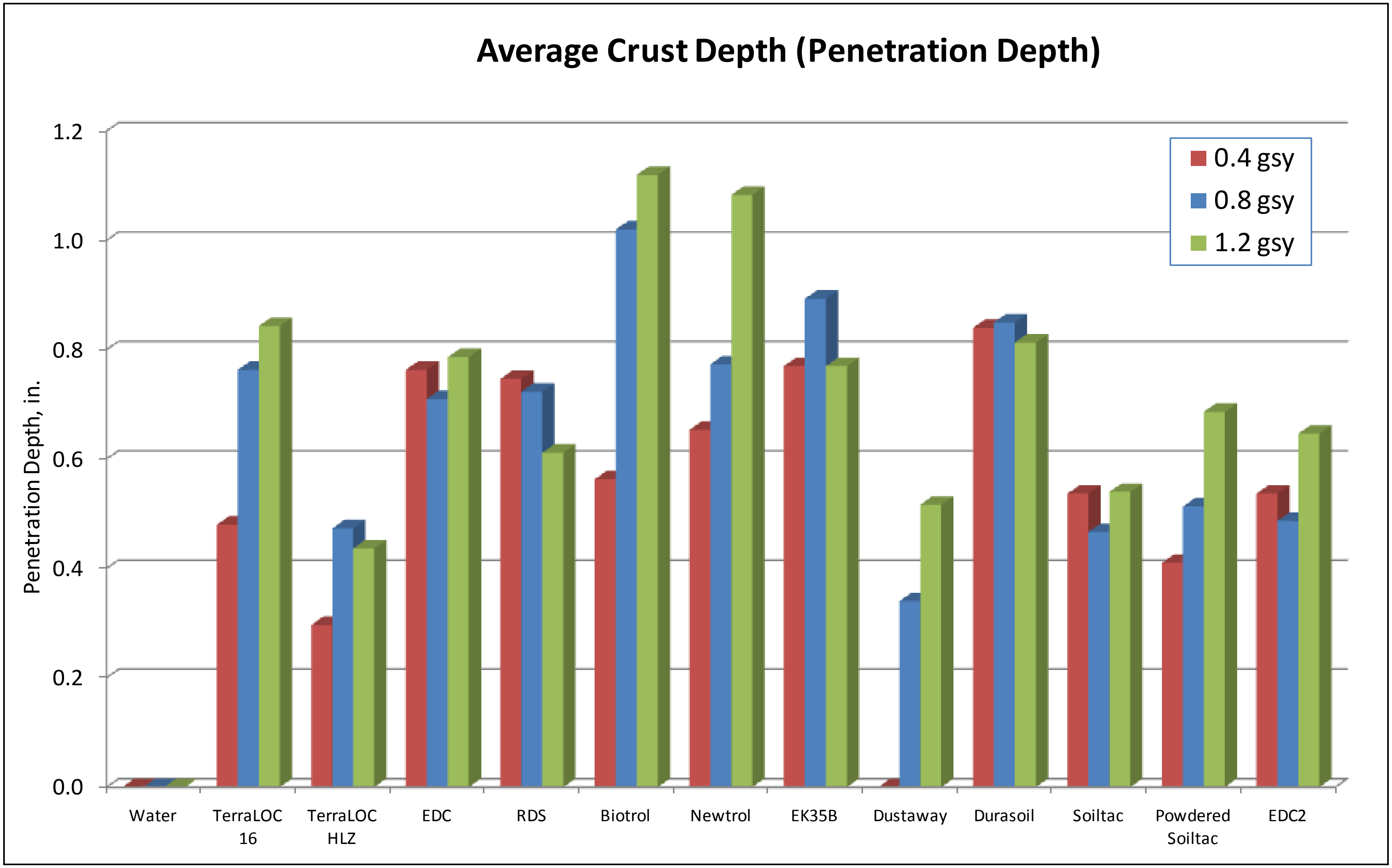


Figure 9. Crust depth or penetration depth of specimens after application and curing.

Discussion of laboratory testing

As expected, the control specimens, those treated with water only, had the most severe surface erosion. All products performed better than the control specimens. The air impingement testing provided an indicator of the optimal concentration required by allowing comparison of the test results of the three concentrations used.

As shown in Figure 10, the results of the two evaluation methods, the erosion potential and optical concentration, were similar. This graph depicts the polynomial correlation of the two methods. This plot of the data collected with the two methods for all three concentrations results in a coefficient of determination, R^2, of 0.84.

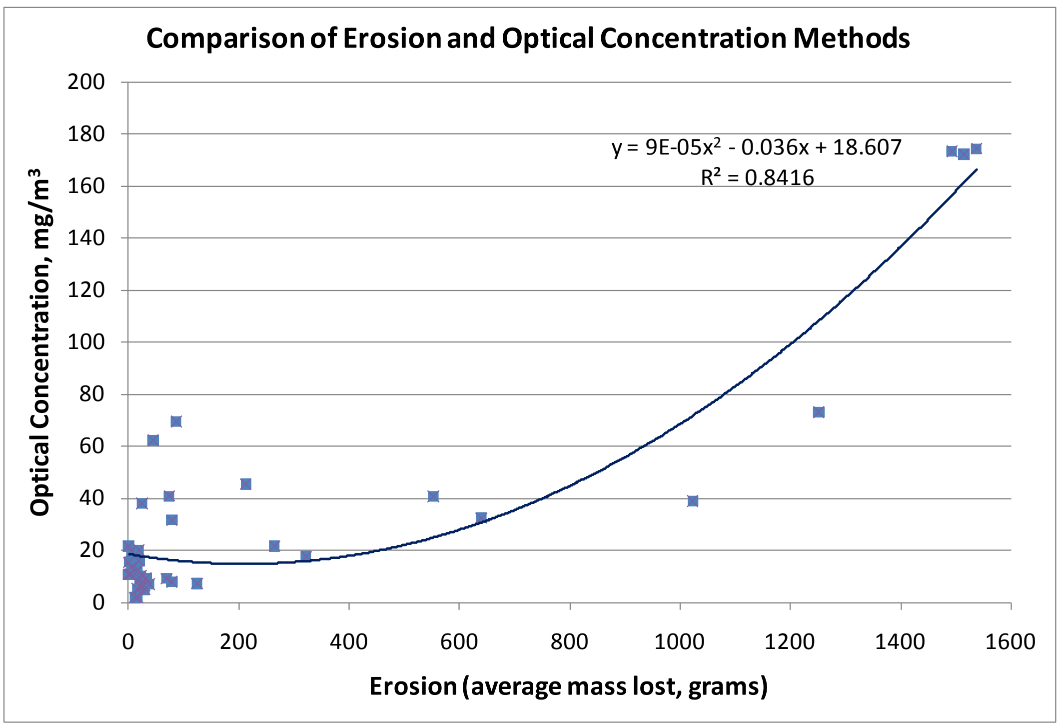


Figure 10. Comparison between the two evaluation methods.

As a general rule for the hard-crust palliatives, a higher concentration led to better dust abatement and thus less mass lost from the specimen. This is consistent with visual observations of these products (photos in Appendix A). On the other hand, the soft-crust, oil-based products actually performed better with lower concentration of product. This result may be caused by the slow absorption rate of these products, leading to excess product running off the specimen rather than being absorbed.

The following paragraphs describe the application details of each palliative tested. Many of the products described below had surfactants or other substances that caused bubbles or foaming in the palliatives, which displaced the loose sand grains upon application and formed small cavities on the surface of the specimens. At lower concentrations, these cavities remained open, exposing loose sand. For higher concentrations, more product was placed onto the specimens, and the cavities were filled in with product. The crusts for these specimens were hard and brittle, with a highly defined transition between the treated and untreated sand. As long as the sand crust was intact, the palliatives were effective at dust abatement. If the crusts were to be broken, the loose sand would easily blow out of the specimens.

TerraLOC® 16

TerraLOC® 16 was easy to mix but was very foamy when mixed. The product was easily absorbed by the soil but formed several cavities in the soil due to the foam. These cavities were less frequent for higher concentrations and would often be filled in with product so that there was no exposed soil. The exposed sand was easily blown away in the air impingement testing. As shown in the photographs after the penetration depths were measured, these crusts did not break easily but came apart in large pieces when they did break. This characteristic will cause a high FOD potential on a helipad if the crust is penetrated.

For TerraLOC® 16, a direct relationship between application concentration and performance was observed and confirmed with the three performance quantification methods. Increases in product concentration led to less soil erosion, lower optical concentration values, and higher penetration depths.

TerraLOC® HLZ

TerraLOC® HLZ did not absorb well because of the laboratory spraying mechanism. The product was extremely thick and rolled on the surface rather than immediately penetrating. Irregular cavities were formed on the surface after application. These cavities were less frequent for higher concentrations and would often be filled in with product so that there was no exposed soil. The exposed sand was easily blown away in the air impingement testing. As shown in the photographs after the penetration depths were measured (Figure A8), these crusts did not break easily but came apart in large pieces when they did break. This type of breakage will cause a high FOD potential on a helipad if the crust is penetrated.

For TerraLOC® HLZ, a direct relationship between application concentration and performance was observed. Increases in product concentration led to less soil erosion and lower optical concentration values. However, the crust depth did not follow the same trend. The penetration depth was actually lower for the 1.2 gsy than for the 0.8 gsy specimen, possibly because the product was so thick and may have runoff the specimen before being absorbed.

EDC™ and EDC2

EDC™ was very thick and slow to absorb. Some runoff occurred at concentrations of 0.8 gsy and 1.2 gsy. Some cavities were formed during application, but the product seeped into the cavities so that there was no loose soil. The crust was very soft and crumbled easily, with a poorly defined transition between treated and untreated sand. Although more product did not affect the penetration depth significantly, more product appeared to cause a moister crust that was not stable enough to withstand the air impingement tests (Figure A10). The optical concentration measurements did not vary significantly among the different concentrations. Because the treated surface was held together with these palliatives, the eroded surface particles were too large to be detected by the HAZDUST III sensor.

EDC2 was also tested. It was similar to the original EDC™ during application, and the erosion and optical concentrations results were similar as well. The penetration depth was lower for the EDC2 than the original EDC™. It should be noted, however, EDC2 was not tested during the same time period as the other products. This product was received and tested in February 2010, while the original EDC™ was tested in September 2009. Although formulated to be effective at a wider range of temperatures, the colder temperature during testing may have had an effect on the penetration depth.

RDS

RDS was similar to EDC™. It was very thick and slow to absorb and difficult to clean off the application equipment. Some runoff occurred at concentrations of 0.8 gsy and 1.2 gsy. The penetration depth was actually lower at

1.2 gsy, possibly due to the thick product running off the surface of the specimen. Some cavities were formed during application, but the product seeped into the cavities so that there was no loose soil. The crust was very soft and crumbled easily, with a poorly defined transition between treated and untreated sand. More product appeared to cause a moister crust that was not stable enough to withstand the air impingement tests (Figure A13). The optical concentration measurements did not vary significantly among the different product concentrations. Because the treated surface was held together with these palliatives, the eroded surface particles were probably too large to be detected by the HAZDUST III sensor.

Biotrol

Biotrol was easy to mix but was very foamy. The product was easily absorbed by the soil but formed several cavities in the soil due to the foam. These cavities were less frequent for higher concentrations and would often be filled in with product so that there was no exposed soil. The exposed sand was easily blown away in the air impingement testing. The crust was not brittle but was firm with flaky layers.

For Biotrol, the increase in concentration did not significantly affect erosion or optical concentration data. According to the erosion and optical concentration data, the product was effective even at the lowest concentration, 0.4 gsy. The penetration depth increased as the concentration increased, and at 1.2 gsy, the crust was the thickest of all the products tested.

Newtrol™

Newtrol™ was easily absorbed by the soil but formed several cavities in the soil during application. These cavities were less frequent and smaller for higher concentrations. The exposed sand was easily blown away in the air impingement testing. The crust was not brittle, but firm with flaky layers.

Increasing the concentration from 0.4 to 0.8 gsy significantly decreased the erosion. Little change was seen by increasing the concentration to 1.2 gsy. However, the optical concentration measurement was the highest for the 0.8 gsy concentration. The penetration depth increased with increasing concentration.

EK35B

EK35B, another oil-based, soft-crust product similar to RDS and EDC™, appears to be effective at all three concentrations according to both of the evaluation methods. The surface erosion and optical concentration measurements of EK35B did not change much with changing concentrations. The penetration depth did not vary significantly, changing only 0.1 in. among the three concentrations.

Dustaway®

Dustaway® is a soft-crust palliative that is very thin and absorbs well. Cavities are formed during spraying but are smaller though more frequent when the application concentration is increased. The crust was very soft and fell apart easily. At 0.4 gsy, no crust remained after the air impingement testing.

Adding more product appears to be more effective for dust abatement. The average surface erosion decreased significantly with increasing concentration; the average optical concentration decreased with increasing concentrations. Increasing the product concentration from 0.4 gsy to 0.8 gsy dramatically improved the surface-erosion and penetration-depth results. The surface erosion decreased by 1239.3 g, and the optical concentration decreased by 71.3 mg/m^3. The increased concentration also greatly improved the penetration depth; at 0.4 gsy, the crust was not measurable because it had eroded away, but the crust had increased to 0.3 in. for 0.8 gsy and 0.5 in. for 1.2 gsy.

Durasoil®

Durasoil® is a soft-crust palliative, but it does not behave like the oil-based products. Adding more product appears to be more effective at dust abatement. The average surface erosion decreased significantly with increasing concentration, and the average optical concentration decreased with increasing concentrations. Increasing the concentration did not increase the penetration depth significantly, but the density of product on the surface may have increased to create a stronger barrier to surface erosion. Additionally, these specimens were cured for 24 hr. In the previous laboratory testing by Rushing et al. (2007), increasing the cure time from 1 hr to 48 hr decreased the surface erosion for 0.2 and 0.4 gsy specimens. More cure time may be required for Durasoil® so that the surface particles can bind effectively to withstand the air impingement testing.

Soiltac®

Soiltac® is easy to mix but difficult to clean off the spraying apparatus if the product is allowed to sit for a short period of time. It absorbs well in the soil but causes cavities during application. These cavities are smaller for greater concentrations. The crust is very hard and brittle. At application concentrations of 0.8 and 1.2 gsy, the crust was very difficult to remove from the specimen container.

Increasing the concentration gave better erosion and optical concentration results. The increase in concentration did not affect the penetration depth much, with only a 0.07-in. change among the three concentrations.

Powdered Soiltac®

Powdered Soiltac® was slightly difficult to mix because it was difficult to get the powder chunks to dissolve. The product was easily absorbed by the soil but formed several cavities in the soil due to the foam. These cavities were less frequent for higher concentrations and would often be filled in with product so that there was no exposed soil. The exposed sand was easily blown away in the air impingement testing. As shown in the photographs after the penetration depths were measured, these crusts did not break easily but came apart in large pieces when they did break. This type of breakage will cause a high FOD potential on a helipad if the crust is penetrated.

Increasing the product concentration increased the penetration depth and improves the erosion data. The optical concentration did not vary much between the 0.8 and 1.2 gsy specimens.

4 Field Testing of Dust Palliatives

Dust palliatives tested in the laboratory were also subjected to field testing. The field tests were executed at the U.S. Marine Corps Command (MCAS), Yuma, AZ, on an area of open desert immediately north of the Auxiliary 2 paved landing zone. This area was the same as the one used in 2005 (Rushing et al. 2006). As shown in Figure 11, the native vegetation had recovered in the area, and only minimal grading of the site was required. The dust palliatives were applied to the helipads, cured for at least 42 hr, and subjected to live flight testing of UH-1, CH-46, and CH-53 aircraft during 16–17 April 2010 to allow researchers to evaluate the products for a range of aircraft weights and rotor diameters.

Figure 11. Overview of site prior to testing.

A timeline of the construction, palliative application, and flight testing can be found in Table 4.

Test site preparation and characterization

The area was graded using a John Deere 772D motor grader to remove vegetation (Figure 12). A John Deere 544K four-wheel drive bucket loader was used to further level the surface prior to palliative application. Other equipment included a Gradall JLG G6-42P forklift for loading and unloading material and equipment, two Polaris Ranger utility carts for transporting equipment, a 4,000-gal water truck for storing/retrieving water for dilution and rinsing equipment. A skid-mounted Finn hydroseeder was used to distribute the dust palliative onto the helipads, and a 7-ton Medium Tactical Vehicle Replacement (MTVR) was used for transporting the hydroseeder.

Table 4. Timeline of events.

Date	Event
8 April 2010	Rental equipment arrival.
9 April 2010	Clearing of site and initial products begin to arrive.
10 April 2010	Finish clearing of site and helipad layout; remaining products arrive.
11 April 2010	Test site characterization and application of Soiltac® on helipad 13.
12 April 2010	Application of Soiltac® on helipad 11, powdered Soiltac® on helipad 12, and Newtrol™ on helipad 7.
13 April 2010	Application of TerraLOC 16 on helipad 2, TerraLOC HLZ on helipad 3, Biotrol on helipad 6, and EDC™ on helipad 4.
14 April 2010	Application of EK35B on helipad 8, Dustaway® on helipad 9, Durasoil® on helipad 10, RDS on helipad 5. Installation of anchors for dust collectors.
15 April 2010	Postapplication test site characterization and painting of numbers on helipads.
16 April 2010	CH-46, partial CH-53, and UH-1 flight testing.
17 April 2010	Remaining CH-53 flight testing.

Figure 12. Initial clearing of test site with motor grader.

Soil classification

Soil specimens were collected from two test helipads, Pads 2 and 4, and subjected to a sieve analysis and Atterberg limit tests. The gradation curve for the soil is plotted in Figure 1. The soil was classified as a poorly graded sand with silt (SP-SM) according to the Unified Soil Classification System (ASTM 1998).

Layout of test site

Thirteen helipads were constructed for this exercise, as shown in Figure 13. Each helipad was constructed to be a 150-ft by 150-ft square with 150-ft untreated transition/buffer zones for separation. Twelve helipads were used for the actual live flight testing. The last helipad, Pad 13, was constructed as a backup.

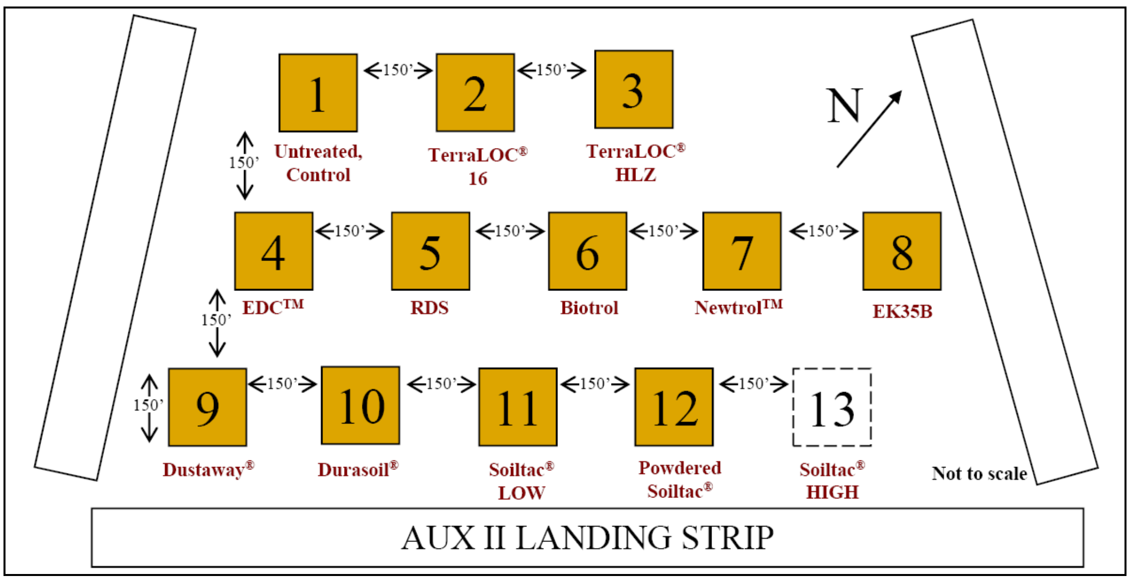


Figure 13. Layout of test site.

Application

Equipment

The skid-mounted Finn hydroseeder was placed onto the Medium Tactical Vehicle Replacement (MTVR) for transportation (Figure 14). A Finn trailer-mounted hydroseeder was also available but was not used, as its capacity was smaller than that of the skid-mounted unit. Specifications for the two Finn hydroseeders are listed in Table 5.

Both hydroseeder models were equipped with both hose and tower gun application equipment. Mechanical agitation of dust palliatives was available in both models.

Figure 14. Using the fork lift to place the skid-mounted hydroseeder on the MTVR.

Table 5. Hydroseeder specification data.

Component	Skid-Mounted	Trailer-Mounted
Tank Capacity, gal	1,180	920
Empty Weight, lb	4,480	5,420
Working Weight, lb	16,080	14,670
Width, in.	80	85
Length, in.	154	194
Height, in.	101	108
Engine	33.5 HP Kubota V1505	33.5 HP Kubota V1505
Pump	4 in. x 2 in. Centrifugal Pump, 170 gpm @ 100 psi	4 in. x 2 in. Centrifugal Pump, 170 gpm @ 100 psi
Fuel Capacity, gal	15	14
Distribution System	Hose, Tower Gun, or Distribution Bar	Hose, Tower Gun, or Distribution Bar

Application protocol

Helipads were treated with dust palliatives 11–14 April 2010. All dust palliatives can be seen in Figure 15. Because of the large volume of palliative required on most helipads, dust palliatives were applied with the skid-mounted hydroseeder to reduce the number of times required to refill. If water was necessary, it was always put into the tank prior to the addition of dust palliative.

Figure 15. Dust palliatives.

Initially, dust palliatives were carefully applied with the manually controlled hose so that an even surface coat was achieved. This application was followed by a second, in which technicians used the tower gun mounted on top of the hydroseeder to spray the remainder of the palliative in the tank onto the helipad. All applications were placed topically. Manpower required for the initial application with the hose was a minimum of three men, but often five or six men were available and assisted with the hose (Figure 16). Manpower required for the tower gun application was two men, one to drive the MTVR and one to operate the tower gun (Figure 17Figure 17). The MTVR was driven at a speed of approximately 5 mph around the perimeter of the helipad until all palliative was applied.

Helipad 1

The first helipad was used as the control to which the performances of the helipads treated with palliatives were compared. Water was used as the standard for comparison in the laboratory but not in the field, because

Figure 16. Application of dust palliative using the hose method.

Figure 17. Application of dust palliative using the tower gun method.

evaporation would occur at different rates between tests. This control helipad, therefore, remained untreated so that it could remain constant throughout the entire field test.

Helipad 2

Helipad 2 was treated with TerraLOC® 16 diluted by adding 3 parts water to 1 part TerraLOC® 16. The actual product application rate was 0.2 gsy, and the diluted application rate was 0.8 gsy. The diluted solution was created by placing 250 gal of product and 750 gal of water into the skid-mounted hydroseeder and mixing the solution for approximately 5 min prior to application. This process was completed twice to meet the quantity required for a diluted application rate of 0.8 gsy. It took 1.45 hr to complete the entire filling and application process, with an average of 17 min required to fill one tank and an average of 26 min for an application of one tank. The mixture was thin and sprayed easily and quickly. However, the surfactants in the product caused bubbles in the mixture, which resulted in cavities in the surface after application. These cavities were covered with palliative after the entire application was completed. During the application process, the ambient temperature was 57°F, the surface temperature was 70°F, and the wind speed was less than 5 mph.

Helipad 3

Helipad 3 was treated with TerraLOC® HLZ, which was applied neat at a product application rate of 0.3 gsy or 750 gal per helipad. TerraLOC® HLZ was shipped in a ready-to-use kit that includes a pump, sprayer apparatus with a nozzle, and prediluted solution (Figure 18). Prior to application, the vendor provided training on how to use the kit, which took approximately 5 min. The required manpower for the application process was four men, and the application took 1.37 hr to complete. The hose was difficult to operate and kinked easily. Pressure at the nozzle was difficult to maintain with the pump provided. The solution was much thicker than the TerraLOC® 16 and did not penetrate well or coat evenly. After completion of the application, many spots had not been treated with the product (Figure 19). During the application process, the ambient temperature was 70°F, the surface temperature was 101°F, and the wind speed was less than 5 mph.

Figure 18. TerraLOC® HLZ application kit.

Figure 19. Uneven coverage using the TerraLOC® HLZ kit.

Helipad 4

Helipad 4 was treated with EDC™, which was applied neat at an application rate of 0.4 gsy or 1000 gal per helipad. EDC™ was packaged in cardboard totes with plastic containers inside them (Figure 20); the packaging did not affect the pumping of the product out of the totes. It took 1.08 hr to complete the entire filling and application process, with 35 min required to fill one tank and 30 min for an application of one tank. Only one tank was required. The product was easy to apply and created an even coat with no exposed sand after the application process. During the application process, the ambient temperature was 83°F, the surface temperature was 108°F, and the wind speed was less than 5 mph.

Figure 20. Cardboard packaging for EDC™.

Helipad 5

Helipad 5 was treated with RDS, which was applied neat at an application rate of 0.4 gsy or 1000 gal per helipad. It took 43 min to complete the entire filling and application process, with 13 min required to fill one tank and 30 min for an application of one tank. Only one tank was required. The product was easy to apply and created an even coat with no exposed sand after the application process. During the application process, the ambient temperature was 83°F, the surface temperature was 108°F, and the wind speed was approximately 8 mph.

Helipad 6

Helipad 6 was treated with Biotrol diluted by adding 2 parts water to 1 part Biotrol. The actual product application rate was 0.27 gsy, and the diluted application rate was 0.8 gsy. The diluted solution was created by placing 333 gal of product and 666 gal of water into the skid-mounted hydroseeder and mixing the solution for approximately 5 min prior to application. This process was completed twice to meet the quantity required for a diluted application rate of 0.8 gsy. It took 1.32 hr to complete the entire filling and application process, with an average of 20 min required to fill one tank and an average of 19 min for an application of one tank. The mixture was thin and sprayed easily and quickly. However, the surfactants in the product caused some bubbles in the mixture, which resulted in cavities in the surface after application. These cavities were filled after the application was completed. During the application process, the ambient temperature was 77°F, the surface temperature was 116°F, and the wind speed was less than 5 mph.

Helipad 7

Helipad 7 was treated with Newtrol™, which was applied neat at an application rate of 0.8 gsy or 2000 gal per helipad. It took 1.53 hr to complete the entire filling and application process, with 26 min required to fill one tank (1000 gal of product) and 19 min for an application of one tank. This process was completed twice to meet the quantity required for a diluted application rate of 0.8 gsy. The product was easy to apply and created an even coat with no exposed sand after the application process. However, the surfactants in the product caused some bubbles in the mixture, which resulted in cavities in the surface after application. These cavities were filled after the application was completed. During the application process, the ambient temperature was 77°F, the surface temperature was 97°F, and the wind speed, ranging from 10 to 20 mph, was higher for the application period for this helipad compared with the other helipads.

Helipad 8

Helipad 8 was treated with EK35B, which was applied neat at an application rate of 0.4 gsy or 1000 gal per helipad. It took 1.2 hr to complete the entire filling and application process, with 36 min required to fill one tank and 36 min for an application of one tank. Only one tank was required. The product was easy to apply and created an even coat with no exposed sand after the application process. It took approximately 2 min after initial application for the product to completely absorb in the sand. During the application process, the ambient temperature was 63°F, the surface temperature was 68°F, and the wind speed was less than 5 mph.

Helipad 9

Helipad 9 was treated with Dustaway® diluted by adding 3 parts water to 1 part product. The actual product application rate was 0.3 gsy, and the diluted application rate was 1.2 gsy. The diluted solution was created by placing 250 gal of product and 750 gal of water into the skid-mounted hydroseeder and mixing the solution for approximately 5 min prior to application. This process was completed three times to meet the quantity required for a diluted application rate of 1.2 gsy. It took 1.65 hr to complete the entire filling and application process, with an average of 15 min required to fill one tank and an average of 17 min for an application of one tank. The mixture was thin and sprayed easily and quickly. During the application process, the ambient temperature was 76°F, the surface temperature was 105°F, and the wind speed was less than 5 mph.

Helipad 10

Helipad 10 was treated with Durasoil®, which was applied neat at an application rate of 0.4 gsy or 1000 gal per helipad. It took 51 min to complete the entire filling and application process, with 19 min required to fill one tank and 32 min for an application of one tank. Only one tank was required. The product was easy to apply and created an even coat with no exposed sand after the application process. During the application process, the ambient temperature was 85°F, the surface temperature was 115°F, and the wind speed was less than 5 mph.

Helipad 11

Helipad 11 was treated with Soiltac® diluted by adding 3 parts water to 1 part product. The actual product application rate was 0.2 gsy, and the diluted application rate was 0.8 gsy. The diluted solution was created by placing 250 gal of product and 750 gal of water into the skid-mounted hydroseeder and mixing the solution for approximately 5 min prior to application. This process was completed twice to meet the quantity required for a diluted application rate of 0.8 gsy. It took 1.3 hr to complete the entire filling and application process, with an average of 22 min required to fill one tank and an average of 16 min for an application of one tank. However, the surfactants in the product caused bubbles in the mixture, which resulted in cavities in the surface after application. These cavities were filled after the application was completed. During the application process, the ambient temperature was 57°F, the surface temperature was 70°F, and the wind speed was less than 5 mph. It should be noted that some vegetation was remaining in the helipad on the east corner and in a few areas on the east side that had been treated with polymer in 2005.

Helipad 12

Helipad 12 was treated with powdered Soiltac® at a diluted rate of 1.2 gsy. Powdered Soiltac® is packaged in 55 lb bags and is mixed at a ratio of 1.03 lb/yd^2. The diluted solution was created by placing approximately 15.7 bags (863.5 lb) of the powdered Soiltac® with 1000 gal of water into the skid-mounted hydroseeder and mixing the solution for approximately 5 min prior to application. This process was repeated 3 times to meet the quantity required (47 lb palliative and 3000 gal water) for a diluted application rate of 1.2 gsy. It took 1.38 hr to complete the entire filling and application process with an average of 15 min required to fill one tank and an average of 12 min for an application of one tank. The powdered form was similar to its liquid counterpart but appeared slightly thicker. Some puddling was evident immediately after spraying, and it took approximately 10 min for the liquid to absorb in the sand. After the last application, some powder that had not dissolved remained on the bottom of the tank, indicating that more time is required for the agitation of the mixture.

Helipad 13

Helipad 13 was treated with Soiltac® diluted by adding 3 parts water to 1 part Soiltac®. The actual product application rate was 0.3 gsy, and the diluted application rate was 1.2 gsy. The diluted solution was created by placing 250 gal of product and 750 gal of water into the skid-mounted hydroseeder and mixing the solution for approximately 5 min prior to application. This process was repeated three times to meet the quantity required for a diluted application rate of 1.2 gsy. It took 2.27 hr to complete the entire filling and application process, with an average of 20 min required to fill one tank and an average of 13 min for an application of one tank. Some puddling was evident immediately after spraying, and it took approximately 10 min for the liquid to soak in (Figure 21). During the application process, the ambient temperature was 74°F, the surface temperature was 105°F, and the wind speed was less than 5 mph. It should be noted that some 2-in. to 3-in. pieces of palliative (left from the testing in 2005) were too difficult to be completely removed (Figure 21).

Figure 21. Puddling of Soiltac® after spraying.

After application

A summary of the application rates, price per gallon, and price per helipad is listed in Table 6. After the palliatives were applied to all helipads, they were allowed to cure for at least 42 hr prior to live flight testing. Refer to the timeline in Table 4 for more details regarding curing time lengths for all products. In preparation for the tests, numbers were painted onto each helipad for the pilots, as shown in Figure 22.

Nuclear density and moisture measurements

Nuclear density and moisture measurements were collected with a Troxler® 3430 nuclear gage (Figure 23). The gage contains two radioactive sources: Cesium-137 for density measurement and Smericium-241:Beryllium for determining moisture content. Density measurements were taken in the 6-in. direct transmission mode according to American Society for Testing and Materials (ASTM) D2922 (2004a). Moisture contents were obtained using procedures outlined in ASTM D3017 (2004b).

Measurements were taken in the center of each helipad and also in the center of the buffer zone between helipads. Data were collected prior to

Table 6. Product application with approximate pricing of products as of May 2010.

Product	Dilution [1]	Diluted Application Rate	Volume of Water (gal)	Volume of Product (gal)	Price per gallon [2]	Price per helipad
TerraLOC® 16	3:1	0.8	1500.0	500	$4.93	$2,465
TerraLOC® HLZ	Neat	0.3	0.0	750	$13.80	$10,350
EDC™	Neat	0.4	0.0	1000	$9.00	$9,000
RDS	Neat	0.4	0.0	1000	$3.81[c]	$3,811 [3]
Biotrol	2:1	0.8	1333.3	667	$9.63	$6,423
Newtrol™	Neat	0.8	0.0	2000	$6.87	$13,740
EK35B	Neat	0.4	0.0	1000	$7.44	$7,440
Dustaway®	3:1	1.2	2250.0	750	$0.65	$488
Durasoil®	Neat	0.4	0.0	1000	$3.65	$3,650
Soiltac®, low	3:1	0.8	1500.0	500	$5.90	$2,950
Powdered Soiltac®	0.86 lb/gal	1.2	3000.0	2585 lb	$1.95/lb	$5,041

[1] Dilution is listed as parts water to parts product.

[2] Price is for product only; water is not included.

[3] Price was quoted in Canadian funds and has been converted based on exchange rate in May 2010 ($1 Canadian = $0.96 US)

Figure 22. Painting a number in the center of the helipad.

Figure 23. Nuclear density and moisture measurements.

and after application of the dust palliatives. Preapplication data can be found in Table 7, and postapplication data can be found in Table 8.

The average dry density and moisture content of the untreated sections were 105.0 pcf and 0.5%, respectively. The average dry density and moisture content of the treated helipads were 106.9 pcf and 0.9%, respectively. Powdered Soiltac® and Soiltac® helipads had the two greatest increases in dry density, at 9.7 pcf and 5.4 pcf, respectively. The remaining helipads had increases less than 3.6 pcf. However, this variability was also seen for the buffer zones, indicating that the changes were due to a natural variability in the soil. Buffer zone 9-10 had an increase of 7.6 pcf. Dustaway® had the largest increase in moisture content at 1.5%, while the maximum increase for the remaining helipads was 0.6%. However, this discrepancy may also be due to the natural variability because buffer zone 12-13 had a change (decrease) in moisture content of 1.6%.

Near-surface shear strength measurements

Near-surface shear strength at 3 in. to 6 in. was characterized with a Geonor H-60 vane shear (Figure 24). A 25.4-mm by 50.8-mm vane was used for all tests. To run the test, the vane was pressed vertically in the soil until the top of the vane was level with the soil surface. With the graduated scale reading set initially to zero, the device was rotated until the soil provided no resistance to the internal sprint. The reading on the graduated scale was recorded as the in situ strength.

Table 7. Preapplication moisture and density data.

Helipad	Product	Wet Density, pcf	Dry Density, pcf	Moisture, pcf	Moisture, %
Helipad Soil Test Data					
1	Untreated	107.3	107.0	0.3	0.3
2	TerraLOC® 16	99.8	99.8	0.1	0.1
3	TerraLOC® HLZ	103.8	103.6	0.2	0.2
4	EDC™	107.1	106.4	0.7	0.6
5	RDS	105.6	105.0	0.7	0.6
6	Biotrol	107.1	106.6	0.4	0.4
7	Newtrol™	108.1	107.9	0.2	0.2
8	EK35B	107.1	106.4	0.7	0.6
9	Dustaway®	98.1	97.8	0.3	0.3
10	Durasoil®	110.1	109.7	0.4	0.4
11	Soiltac®, low	107.3	107.0	0.3	0.3
12	Powdered Soiltac®	99.4	98.3	1.1	1.1
13	Soiltac®, high	110.1	108.9	1.1	1.0
	Average	105.5	105.0	0.5	0.5
	Standard Deviation	4.0	3.9	0.3	0.3
Buffer Zone Data					
1 - 2	Buffer Zone	106.7	106.0	0.8	0.7
2 - 3	Buffer Zone	106.7	106.3	0.4	0.4
4 - 5	Buffer Zone	105.9	105.7	0.2	0.2
5 - 6	Buffer Zone	107.5	106.8	0.7	0.6
6 - 7	Buffer Zone	104.9	104.3	0.5	0.5
7 - 8	Buffer Zone	103.9	103.5	0.4	0.4
9 - 10	Buffer Zone	102.9	101.8	1.1	1.1
10 - 11	Buffer Zone	104.9	103.9	0.2	0.2
11 - 12	Buffer Zone	108.7	108.0	0.7	0.6
12 - 13	Buffer Zone	112.4	110.0	2.4	2.2
	Average	106.5	105.6	0.7	0.7
	Standard Deviation	2.7	2.4	0.6	0.6

Table 8. Postapplication moisture and density data.

Helipad	Product	Wet Density, pcf	Dry Density, pcf	Moisture, pcf	Moisture, %
Helipad Soil Test Data					
1	Untreated	107.9	107.0	0.9	0.8
2	TerraLOC® 16	104.1	103.4	0.7	0.6
3	TerraLOC® HLZ	104.0	103.9	0.2	0.2
4	EDC™	110.3	109.3	1.0	0.9
5	RDS	106.3	105.3	1.0	1.0
6	Biotrol	105.8	105.2	0.7	0.6
7	Newtrol™	110.0	109.1	0.9	0.8
8	EK35B	110.3	109.0	1.4	1.2
9	Dustaway®	105.0	103.2	1.8	1.8
10	Durasoil®	109.4	108.9	0.4	0.4
11	Soiltac®, low	106.5	105.8	0.7	0.6
12	Powdered Soiltac®	109.0	108.0	1.0	0.9
13	Soiltac®, high	113.1	111.4	1.7	1.5
	Average	107.8	106.9	1.0	0.9
	Standard Deviation	2.8	2.6	0.5	0.4
Buffer Zone Data					
1 - 2	Buffer Zone	106.6	106.0	0.5	0.5
2 - 3	Buffer Zone	107.7	107.0	0.7	0.6
4 - 5	Buffer Zone	102.4	101.7	0.7	0.6
5 - 6	Buffer Zone	107.9	107.2	0.7	0.6
6 - 7	Buffer Zone	107.0	106.9	1.0	0.9
7 - 8	Buffer Zone	107.5	106.6	0.9	0.8
9 - 10	Buffer Zone	110.3	109.4	0.9	0.8
10 - 11	Buffer Zone	105.3	104.4	0.9	0.8
11 - 12	Buffer Zone	111.4	110.2	1.2	1.1
12 - 13	Buffer Zone	107.5	106.7	0.8	0.7
	Average	107.4	106.6	0.8	0.7
	Standard Deviation	2.5	2.4	0.2	0.2

Figure 24. Using the Geonor H-60 vane shear to collect near-surface strength measurements.

Remolded strengths were taken by zeroing the device and rotating it multiple times in the disturbed soil and recording the location of the dial. As recommended by the manufacturer, all readings were multiplied by 0.5 to adjust for using the large vane.

Measurements were taken in the center of each helipad and also in the center of the buffer zone between helipads. Data were collected prior to and after application of the dust palliatives to determine the effect of the dust palliatives. Preapplication data can be found in Table 9 and post-application data can be found in Table 10.

Only the palliatives that formed a hard brittle crust had an effect on the shear strength values. These helipads had increases ranging from 7 to 39 kPa, and included TerraLOC® 16 (7 kPa), TerraLOC® HLZ (17 kPa) Soiltac® at 0.8 gsy (26 kPa), powdered Soiltac® (39 kPa), and Soiltac® at 1.2 gsy (37 kPa). The remaining helipads had increases less than 4 kPa.

Dynamic cone penetrometer (DCP) measurements

DCP measurements were taken to measure the in situ soil strength (Figure 25). The tests were conducted according to the procedure described by ASTM D6951 (2003). The DCP had a 60-deg cone with a base diameter of 0.79 in. The test procedure involved placing the DCP cone point on the surface and recording a baseline measurement to the nearest

Table 9. Preapplication Geonor vane shear data.

Helipad	Product	Vane Size	In Situ Strength, kPa	Remolded Shear Strength, kPa		Average Remolded, kPa
				Remolded 1	Remolded 2	
1	Untreated	large	3.0	4.0	5.0	4.5
2	TerraLOC® 16	large	3.0	4.0	5.0	4.5
3	TerraLOC® HLZ	large	3.0	4.0	5.0	4.5
4	EDC™	large	4.0	5.0	5.0	5.0
5	RDS	large	4.0	5.0	6.0	5.5
6	Biotrol	large	3.0	4.0	5.0	4.5
7	Newtrol™	large	7.0	5.0	6.0	5.5
8	EK35B	large	4.0	4.0	5.0	4.5
9	Dustaway®	large	7.0	5.0	5.5	5.3
10	Durasoil®	large	5.0	5.0	6.0	5.5
11	Soiltac®, low	large	4.0	5.0	6.0	5.5
12	Powdered Soiltac®	large	4.0	4.0	5.0	4.5
13	Soiltac®, high	large	3.0	4.0	5.0	4.5
1 - 2	Buffer Zone	large	10.0	7.0	7.0	7.0
2 - 3	Buffer Zone	large	3.0	4.0	5.0	4.5
4 - 5	Buffer Zone	large	4.0	5.0	5.0	5.0
5 - 6	Buffer Zone	large	4.0	4.0	5.0	4.5
6 - 7	Buffer Zone	large	5.0	4.0	5.0	4.5
7 - 8	Buffer Zone	large	4.0	5.0	6.0	5.5
9 - 10	Buffer Zone	large	7.5	4.0	4.0	4.0
10 - 11	Buffer Zone	large	5.0	5.0	6.0	5.5
11 - 12	Buffer Zone	large	3.0	4.0	5.0	4.5
12 - 13	Buffer Zone	large	7.5	7.5	7.5	7.5

Table 10. Postapplication Geonor vane shear data.

Helipad	Product[a]	Vane Size	In Situ Strength, kPa	Remolded Shear Strength, kPa		Average Remolded, kPa
				Remolded 1	Remolded 2	
1	Untreated	large	7.0	8.0	7.0	7.5
2	TerraLOC® 16	large	10.0	9.0	8.0	8.5
3	TerraLOC® HLZ	large	20.0	5.0	5.0	5.0
4	EDC™	large	3.0	3.0	4.0	3.5
5	RDS	large	4.0	4.0	5.0	4.5
6	Biotrol	large	4.0	5.0	6.0	5.5
7	Newtrol™	large	9.0	6.0	6.0	6.0
8	EK35B	large	4.0	4.0	5.0	4.5
9	Dustaway®	large	8.0	6.0	6.0	6.0
10	Durasoil®	large	5.0	6.0	7.0	6.5
11	Soiltac®, low	large	30.0	5.0	8.0	6.5
12	Powdered Soiltac®	large	43.0	5.0	6.0	5.5
13	Soiltac®, high	large	40.0	5.0	5.0	5.0
1 - 2	Buffer Zone	large	4.0	5.0	5.0	5.0
2 - 3	Buffer Zone	large	4.0	5.0	5.0	5.0
4 - 5	Buffer Zone	large	4.0	5.0	6.0	5.5
5 - 6	Buffer Zone	large	3.0	4.0	5.0	4.5
6 - 7	Buffer Zone	large	3.0	4.0	5.0	4.5
7 - 8	Buffer Zone	large	5.0	5.0	6.0	5.5
9 - 10	Buffer Zone	large	9.0	5.0	5.0	5.0
10 - 11	Buffer Zone	large	7.0	5.0	7.0	6.0
11 - 12	Buffer Zone	large	4.0	4.0	5.0	4.5
12 - 13	Buffer Zone	large	15.0	9.0	10.0	9.5

Figure 25. Collection of DCP data.

5 mm. The 10.1 hammer was then raised and dropped 22.6 in. onto the anvil, which drove the penetrometer rod and cone into the soil. Depth of the cone penetration measurements and number of hammer blows were recorded approximately every inch (25 mm) or whenever any noticeable change in penetration rate occurred. A DCP strength index in terms of penetration per hammer blow was calculated for each measurement interval. The DCP index was then converted to California Bearing Ratio (CBR) percentage using the correlation described in Equation 1, where DCP is in mm/blow. Multiplying the DCP value by 2 correlates the 10.1-lb hammer to the 17.6-lb hammer for which the relationship was developed. The CBR value ranges from 0% to 100% and provides an index of relative soil strength with depth. DCP data for this report were then entered into a Microsoft Excel spreadsheet formatted to automatically process the data.

$$CBR\left(\%\right)=\frac{292}{DCP^{1.12}} \tag{1}$$

Measurements were taken in the center of each helipad and also in the center of the buffer zone between helipads. Data were collected prior to application of the dust palliatives. Preapplication data can be found in Table 11. Because the dust palliatives did not penetrate past 2 in., no DCP data were taken after dust palliatives were applied.

Table 11. Preapplication dynamic cone penetration data.

Helipad	Product	Depth (in.)	CBR (%)	Depth (in.)	CBR (%)
1	Untreated	surface	1.5	6-24	8.0
2	TerraLOC® 16	surface	0.1	6-24	5.0
3	TerraLOC® HLZ	surface	0.1	6-24	4.0
4	EDC™	surface	2.0	6-24	8.0
5	RDS	surface	1.7	6-24	7.0
6	Biotrol	surface	1.9	6-24	5.0
7	Newtrol™	surface	1.5	6-24	7.0
8	EK35B	surface	1.3	6-24	4.0
9	Dustaway®	surface	2.2	6-24	11.0
10	Durasoil®	surface	2.5	6-24	10.0
11	Soiltac®, low	surface	1.3	6-24	8.0
12	Powdered Soiltac®	surface	6.0	6-24	12.0
13	Soiltac®, high	surface	6.0	6-24	10.0
1 - 2	Buffer Zone	surface	3.0	6-24	7.0
2 - 3	Buffer Zone	surface	1.3	6-24	4.0
4 - 5	Buffer Zone	surface	1.9	6-24	6.0
5 - 6	Buffer Zone	surface	1.2	6-24	3.0
6 - 7	Buffer Zone	surface	2.0	6-24	5.0
7 - 8	Buffer Zone	surface	0.1	6-24	4.0
9 - 10	Buffer Zone	surface	1.5	6-24	8.0
10 - 11	Buffer Zone	surface	3.0	6-24	12.0
11 - 12	Buffer Zone	surface	1.7	6-24	8.0
12 - 13	Buffer Zone	surface	0.1	6-24	7.0

The near surface CBR of the loose sand ranged from 0.1% to 6% with an average of 2.2%. The lower sand layer, from 6 in. to 24 in., was higher than the surface, ranging from 4% to 12%, with an average of 7.6%. Helipads 11, 12, and 13 had higher CBR values. Soil treated with palliatives during the last round of testing (Rushing et al. 2006) was found in these areas. It was difficult to remove the previously treated soil completely. Some of the treated soil was covered up with untreated soil, which may be the cause for the slight increase in CBR values.

Palliative penetration depth

Measurements were taken at eight locations on each helipad to evaluate the penetration depth, as can be seen in Table 12. The first four measurements were taken after at least one day of curing, and the last four were measured after the completion of flight testing. TerraLOC® HLZ had the thinnest crust, which was expected because of the thick product and uneven coverage during application. It was also applied at the lowest application rate. The remaining products had average penetration depths of 0.53 in. or higher. Biotrol, Dustaway®, and Newtrol™ all had average penetration depths greater than 1 in., at 1.66, 1.47, and 1.27 in., respectively. The oil-based products, EDC™ and RDS had similar crust thicknesses of 0.69 in. and 0.86 in., respectively. Increasing the Soiltac® from 0.8 gsy to 1.2 gsy resulted in a 0.35-in. thicker crust. Because Soiltac® is a very fast-drying product, the application method (i.e., initial application with the hose and subsequent applications with the tower gun) may have prohibited optimal penetration. The product may have dried and formed a crust between the hose application and the tower application.

Table 12. Palliative penetration depths.

Heli-pad	Product	Crust Thickness (in) [1]								Avg [2]	Stdev [3]
2	TerraLOC® 16	1.00	0.75	0.25	0.75	0.75	0.50	0.25	1.50	0.72	0.41
3	TerraLOC® HLZ	0.75	0.25	0.13	0.13	0.25	0.13	0.25	0.13	0.25	0.21
4	EDC™	0.75	1.00	0.75	1.00	0.50	0.50	0.50	0.50	0.69	0.22
5	RDS	1.25	1.25	1.13	1.13	0.50	0.75	0.38	0.50	0.86	0.37
6	Biotrol	2.00	2.25	1.50	1.75	1.88	1.13	1.75	1.00	1.66	0.43
7	Newtrol™	1.75	1.75	1.50	1.50	0.75	1.50	0.88	0.50	1.27	0.48
8	EK35B	0.75	1.50	1.25	1.50	0.50	0.88	0.50	0.88	0.97	0.41
9	Dustaway®	2.75	2.50	2.13	2.25	0.63	0.50	0.50	0.50	1.47	1.02
10	Durasoil®	1.00	1.25	0.75	1.75	0.63	0.63	0.75	0.88	0.95	0.38
11	Soiltac®, low	1.00	0.25	0.38	0.25	0.50	0.50	0.75	0.63	0.53	0.26
12	Powdered Soiltac®	0.25	0.63	0.38	0.63	0.38	0.38	1.00	1.00	0.58	0.29
13	Soiltac®, high	0.88	0.75	0.38	0.50	1.25	1.50	1.00	0.75	0.88	0.37

[1] The first four crust thickness measurements were taken after at least 1 day of curing, and the last four were taken after flight testing.

[2] Average.

[3] Standard deviation.

Quantitative measurements of dust palliative methods

Dust collectors

Dust collectors were used to provide a quantitative measure of the effectiveness of the dust palliatives. These stationary dust collectors were located approximately 5 ft from the northwest and northeast sides of the helipads. The dust collectors consisted of a filter placed over a wire mesh screen through which a slight vacuum pressure was drawn using an electric pump (Figure 26). The dust collectors were uncovered prior to the initial landing for each helipad, and the filters were removed to be weighed later.

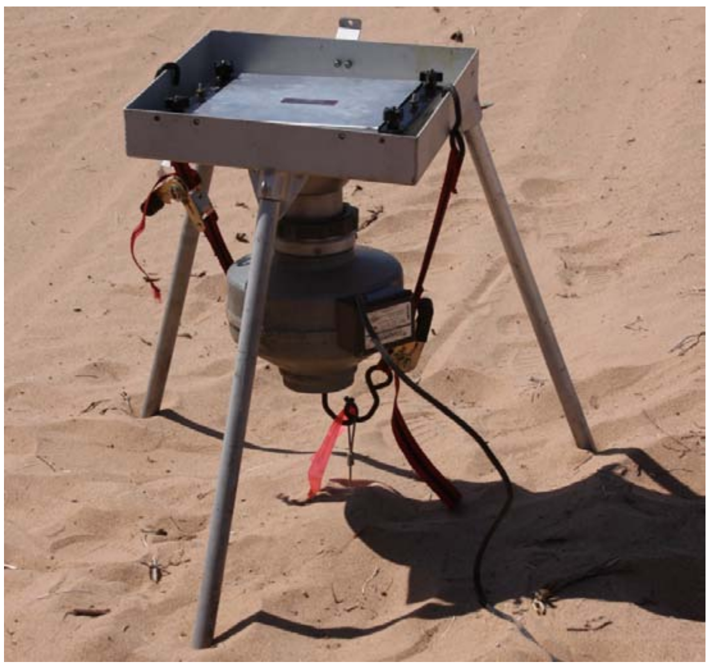


Figure 26. Dust collector in place and ready to use.

Gravity buckets

Gravity buckets were placed in the ground in the north corner of the helipads for the CH-46 and UH-1 flight tests. These gravity buckets consisted of metal paint cans that were moistened with water to trap the collected dust and prevent loss upon liftoff (Figure 27). The gravity buckets were taken back to the lab where the collected dust was oven dried to remove moisture and then weighed.

Figure 27. Gravity buckets used to collect dust at the corner of the helipads.

Pilot evaluation

Pilots were asked to rate the effectiveness of the dust abatement products during the hover sequence, but not during the initial approach. They were asked to compare the treated helipads with the untreated helipads and to provide comments or observations about their experience on each helipad. Rankings for the helipads are included in the following text.

Flight testing

Helipads were subjected to landings with CH-46, UH-1, and CH-53. With the exception of the CH-53, all twelve helipads were tested with all three aircraft. The landing sequence consisted of three landings: the initial landing and two hover sequences for the next two landings. Dust collectors and pilot evaluations were based on the two subsequent landings and departures, not the initial landing, to account for perimeter dust that may have been picked up during the initial landing. Aircraft characteristics are listed in Table 13.

Table 13. Aircraft characteristics.

Aircraft	Length (ft)	Height (ft)	Rotor Diameter (ft)	Min Takeoff Weight (lb)	Max Takeoff Weight (lb)
CH-46	84.3	16.7	51.0	14,770	24,300
UH-1	57.3	14.9	48.0	6,000	10,500
CH-53	99.0	28.3	79.0	35,220	69,750

CH-46

CH-46 rotary-wing flight tests were conducted on 16 April 2010. Three pilots conducted the CH-46 flight tests. Figures B1–B12 depict the CH-46 operations on the helipads.

The dust collection filter data for CH-46 flight testing are shown in Table 14. These data indicate that all palliatives were effective compared to the untreated control helipad, and a 53% to 95% reduction of dust collected was observed. TerraLOC® HLZ had the least amount of reduction at 53%. The remaining palliatives had dust reductions of at least 71%.

Table 14. Amount of dust collected on filters during CH-46 flight testing.

Helipad	Product	NE (grams)	NW (grams)	Average (grams)	Standard Deviation (grams)	Percent Reduction from Control
1	Untreated	5.7	5.2	5.5	0.4	
2	TerraLOC® 16	0.2	0.6	0.4	0.3	93%
3	TerraLOC® HLZ	0.8	4.3	2.6	2.5	53%
4	EDC™	0.5	0.5	0.5	0.0	91%
5	RDS	2.5	0.7	1.6	1.3	71%
6	Biotrol	0.5	0.2	0.3	0.2	94%
7	Newtrol™	0.5	1.0	0.8	0.4	86%
8	EK35B	0.2	1.9	1.1	1.2	81%
9	Dustaway®	0.4	0.2	0.3	0.1	94%
10	Durasoil®	1.0	1.2	1.1	0.1	80%
11	Soiltac®, low	0.2	0.3	0.3	0.1	95%
12	Powdered Soiltac®	0.0	0.8	0.4	0.6	93%

Gravity bucket data are summarized in Table 15. Data collected with the gravity buckets were not consistent with the filter data or the pilot ratings.

The pilot rankings, summarized in Table 16, are consistent with the dust collection data. Helipads ranked in the top 5 by the pilots seem to be efficient at dust abatement. The helipads in this top 5 ranking also have at least 80% reduction in dust collected. The lowest pilot ranking, TerraLOC® HLZ, also had the lowest percent reduction in dust collected (53%).

Table 15. Amount of dust collected in gravity buckets during the CH-46 flight testing.

Helipad	Product	Amount Collected (grams)
1	Untreated	1274.6
2	TerraLOC® 16	5.1
3	TerraLOC® HLZ	57.1
4	EDC™	150.6
5	RDS	3.7
6	Biotrol	10.7
7	Newtrol™	29.7
8	EK35B	5.6
9	Dustaway®	148.5
10	Durasoil®	657
11	Soiltac®, low	26.6
12	Powdered Soiltac®	86.2

Table 16. CH-46 pilot rankings and observations.

Helipad	Product	Pilot Ranking	Test Order	Observations
12	Powdered Soiltac®	1	9	No dust coming up at all. Pad 12 performed better than Pads 9-11.
9	Dustaway®	2	11	Good, no dust on pad.
10	Durasoil®	3	10	Little to no dust. Dust stayed at 1–2 ft.
8	EK35B	4	5	Not much dust; helicopter sinks down, but nothing is flying up.
11	Soiltac®, low	4	12	A little worse than Pad 9. Saw 4- to 5-in.-diam particles flaking off.
6	Biotrol	5	8	Does not break up at all; better than Pad 5.
5	RDS	6	7	Surface is breaking significantly.
2	TerraLOC® 16	7	2	Surface is breaking and causing brownout.
4	EDC™	7	4	Not as good as Pad 2 but better than Pad 3. Surface is soft.
7	Newtrol™	7	6	More dust than Pad 8.
3	TerraLOC® HLZ	8	3	Surface is thinner than Pad 2 and breaks quickly.
1	Untreated	9	1	Not a brownout and not as bad as Afghanistan.

UH-1

UH-1 rotary-wing flight tests were conducted on 16 April 2010. Two pilots conducted the UH-1 flight tests. Figures B13–B24 depict the UH-1 operations on the helipads.

The dust collection filter data for UH-1 flight testing are shown in Table 17. These data indicate that all palliatives were effective compared to the untreated control helipad, and a 14% to 91% reduction of dust collected was observed. Powdered Soiltac® had the least amount of reduction at 14%. However, it should be noted that the UH-1 pilot landed on this helipad nine times, as opposed to the standard three landings for the rest of the helipads. The extra landings caused the amount of dust collected to be artificially higher than that of the other helipads, as can be seen in the pilot rankings. The remaining palliatives had dust reductions of at least 54%.

The dust collected in the gravity buckets are summarized in Table 18. Data collected with the gravity buckets were not consistent with the filter data or the pilot ratings.

Table 17. Amount of dust collected on filters during UH-1 flight testing.

Helipad	Product	NE (grams)	NW (grams)	Average (grams)	Standard Deviation (grams)	Percent Reduction from Control
1	Untreated	6.6	4.9	5.8	1.2	
2	TerraLOC® 16	3.3	1.0	2.2	1.6	63%
3	TerraLOC® HLZ	2.5	2.8	2.7	0.2	54%
4	EDC™	1.7	1.8	1.8	0.1	70%
5	RDS	3.2	1.4	2.3	1.3	60%
6	Biotrol	2.1	1.4	1.8	0.5	70%
7	Newtrol™	0.5	0.5	0.5	0.0	91%
8	EK35B	0.9	1.0	0.9	0.1	83%
9	Dustaway®	1.4	0.7	1.1	0.5	82%
10	Durasoil®	1.0	2.3	1.7	0.9	71%
11	Soiltac®, low	0.8	0.7	0.8	0.1	87%
12	Powdered Soiltac®	2.3	7.6	5.0	3.7	14%

[1] UH-1 pilot landed 9 times, as opposed to the standard 3, on helipad 12 (powdered Soiltac®)

Table 18. Amount of dust collected in gravity buckets during the UH-1 flight testing.

Helipad	Product	Amount Collected (grams)
1	Untreated	154.8
2	TerraLOC® 16	12.3
3	TerraLOC® HLZ	16.3
4	EDC™	25.4
5	RDS	18.8
6	Biotrol	27.1
7	Newtrol™	5.2
8	EK35B	12.8
9	Dustaway®	18.5
10	Durasoil®	39.0
11	Soiltac®, low	19.0
12	Powdered Soiltac®	22.5

Table 19. UH-1 pilot rankings and observations.

Helipad	Product	Pilot Ranking	Test Order	Observations
7	Newtrol™	1	2	Not breaking up. No chunks.
9	Dustaway®	2	5	Skids do not sink as much, is more durable.
10	Durasoil®	2	8	Surface felt firm, but still sinks approximately 2 to 3 in.
8	EK35B	3	3	Surface breaking significantly, skids sinking approximately 4 in.
12	Powdered Soiltac®	4	12	Not a lot of dust, but skids sink in. Not enjoyable to land on. Crust on top breaks in, and is "undercooked."
4	EDC™	5	7	Squishy feel.
11	Soiltac®, low	5	10	Very crusty; 1/4" crust is kicked up; Firmer than the rest of the pads so far (2,3,4,5,7,8,9,10).
2	TerraLOC® 16	6	4	Skids are breaking surface into multiple large pieces.
5	RDS	7	9	Spongy, soft surface.
6	Biotrol	8	11	Breaks under skids.
3	TerraLOC® HLZ	9	6	Breaks apart, but still have a visual.
1	Untreated	10	1	

The dust collected in the gravity buckets are summarized in Table 18. Data collected with the gravity buckets were not consistent with the filter data or the pilot ratings.

CH-53

CH-53 rotary-wing flight tests were conducted on 16–17 April 2010. One pilot conducted the CH-53 flight tests. Figures B25–B33 depict the CH-53 operations on the helipads. Some of the helipads experienced CH-53 flight tests prior to the CH-46 flight tests; these included Dustaway® (helipad 9), Durasoil® (helipad 10), and Soiltac (helipad 11). TerraLOC® HLZ, RDS, and Newtrol™ did not undergo CH-53 flight testing because of the time limitation with the aircraft. The dust collection filter data for CH-53 flight testing are shown in Table 20, and the pilot rankings are listed in Table 21.

Dust collection data and pilot ratings were less consistent with the CH-53 flight testing. The CH-53 had a much greater effect on the helipads than the other two helicopters, and after flight testing with the CH-53, helipads deteriorated quickly.

Table 20. Amount of dust collected on filters during CH-53 flight testing.

Heli-pad	Product	NE (grams)	NW (grams)	Average (grams)	Standard Deviation (grams)	Percent Reduction from Control
1	Untreated	56.6 [1]	8.0	8.0	n/a	
2	TerraLOC® 16	3.2	3.5	3.4	0.2	58%
3	TerraLOC® HLZ	n/a	n/a	n/a	n/a	n/a
4	EDC™	3.7	4.1	3.9	0.3	51%
5	RDS	n/a	n/a	n/a	n/a	n/a
6	Biotrol	2.3	2.0	2.2	0.2	73%
7	Newtrol™	n/a	n/a	n/a	n/a	n/a
8	EK35B	2.4	3.2	2.8	0.6	65%
9	Dustaway®	1.4	1.5	1.5	0.1	82%
10	Durasoil®	1.5	2.0	1.8	0.4	78%
11	Soiltac®, low	0.5	0.4	0.5	0.1	94%
12	Powdered Soiltac®	2.5	4.1	3.3	1.1	59%

[1] The NE dust collector for Pad 1 (untreated) fell over during testing; this value is not used in calculating the average.

Table 21. CH-53 pilot rankings and observations.

Helipad	Product	Pilot Ranking	Test Order	Observations
8	EK35B	1	7	Chunks break up and expose sand; better than Pad 2.
9	Dustaway®	2	2	
2	TerraLOC® 16	3	6	Crust is breaking under skids.
12	Powdered Soiltac®	4	5	Crust holding up better than pads 6 and 4.
6	Biotrol	5	8	Chunks blew.
10	Durasoil®	6	3	
11	Soiltac®, low	7	4	
4	EDC™	7	9	Crust is breaking up more than others.
1	Untreated	8	1	NE dust collector down.
3	TerraLOC® HLZ	Not Tested	N/A	N/A
5	RDS	Not Tested	N/A	N/A
7	Newtrol™	Not Tested	N/A	N/A

Summarized evaluation of palliatives

A summary of the pilot rankings is provided in Table 22. The pilot's viewpoint was considered the most accurate perspective on the performance of the dust palliatives; however, pilot rankings varied among the aircraft. The aircraft type has an effect on the amount of dust generated, which is to be expected. The amount of dust appeared to be proportional to the size, weight, rotor size, and thrust of the aircraft. Testing revealed the effectiveness of many dust palliatives to be very similar, and the pilot rankings corroborated these findings.

A summary of the amount of dust collected on the filters during flight testing is shown as Figure 28, and a summary of the amount of dust collected in the gravity buckets is shown as Figure 29. Materials selected for dust abatement must create an area with minimal visibility loss without introducing potential damage to the aircraft. These materials must also produce desirable results utilizing minimal logistical effort. Data presented in this report present both subjective and quantitative information from the field testing. Both of these types of data can be used to evaluate the effectiveness of the palliatives tested.

As previously done by Tingle et al. (2004), each product was rated using a weighted point system based on four factors (Table 23). Each factor is rated from 1 to 10 and is then multiplied by a constant based on importance. The first factor, resistance to rotor wash, is a reflection on the amount of dust measured using the dust collectors along with the visual observations from the pilots. This is considered the most important factor and is given the highest weighting at 50% of the overall rating. The second factor is the durability of the helipad, which represents 20% of the final rating. This rating reflects the ability of the helipad to withstand environmental changes and occasional traffic. Treated helipads should be able to withstand the effects of rain and wind. The third factor is the FOD potential, which represents 20% of the final rating. This is the observed potential for generating FOD for the operating aircraft, as well as for adjacent parked aircraft. Normally the brittle, hard-crust palliatives are the ones that form FOD, and these palliatives will need to be placed so that the crust is thick enough (at least 1 in.) to prevent breaking from the surface. The fourth factor is the surface condition, which represents 10% of the final rating. It represents the texture of the surface and the impact of the surface on military operations. For example, the helipad must be able to withstand the dragging of hoses during refueling operations.

Table 22. Summary of pilot ranking.

Helipad	Dust Palliative Name	Dilution (Water: Product)	Field Product (gsy)	Field Diluted (gsy)	CH-46	UH-1	CH-53
12	Powdered Soiltac®	0.86 lb/gal	1.03 lb/sq yd	1.2	1	4	4
9	Dustaway®	3:1	0.3	1.2	2	2	2
10	Durasoil®	neat	0.4	0.4	3	2	6
8	EK35B	neat	0.4	0.4	4	3	1
11	Soiltac®, low	3:1	0.2	0.8	4	5	7
6	Biotrol	2:1	0.27	0.8	5	8	5
5	RDS	neat	0.4	0.4	6	7	N/A
2	TerraLOC® 16	3:1	0.2	0.8	7	6	3
4	EDC™	neat	0.4	0.4	7	5	7
7	Newtrol™	neat	0.8	0.8	7	1	N/A
3	TerraLOC® HLZ	neat	0.3	0.3	8	9	N/A
1	Untreated				9	10	8

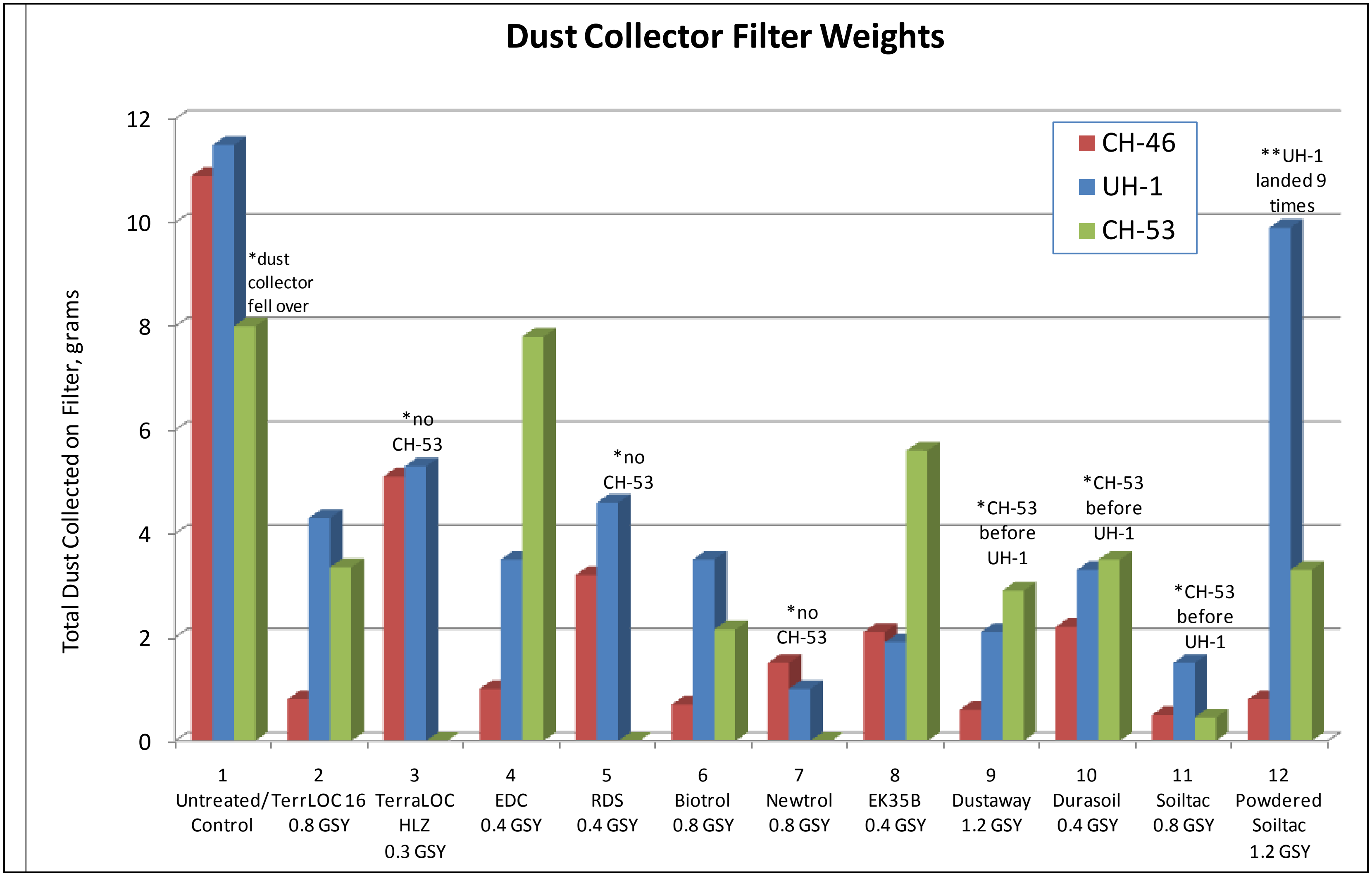


Figure 28. Amount of dust collected on filters during flight testing.

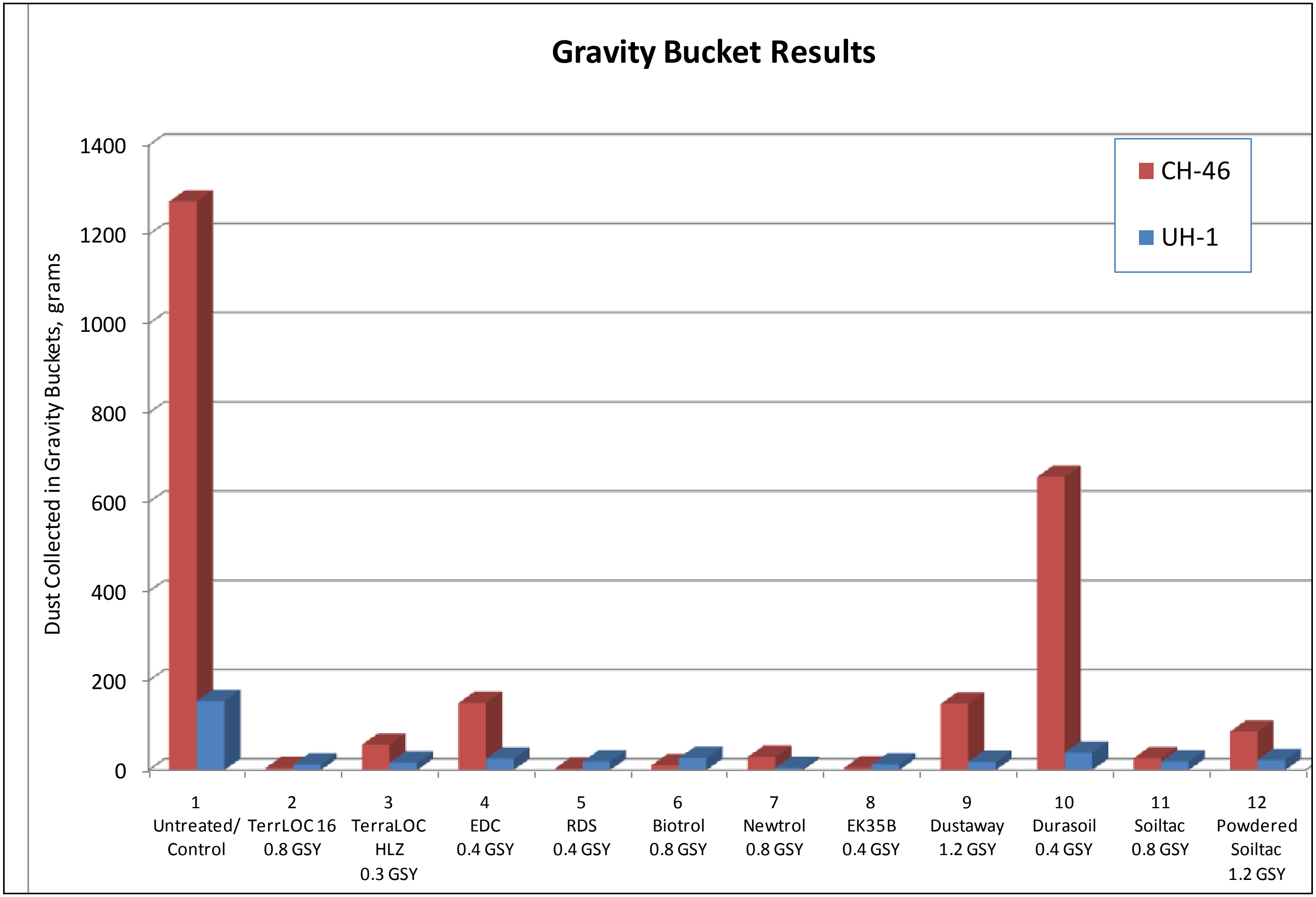


Figure 29. Amount of dust collected in gravity buckets.

Table 23. Weighted palliative ratings.

Heli pad	Palliative	Field Diluted Rate (gsy)	Resistance to Rotor Wash (Rating x 5)	Durability of Helipad (Rating x 2)	FOD Potential (Rating x 2)	Surface Condition (Rating x 1)	Weighted Rating (Up to 100)
8	EK35B	0.4	50	20	20	10	100
9	Dustaway®	1.2	50	20	20	10	100
10	Durasoil®	0.4	45	20	20	10	95
4	EDCTM	0.4	40	20	20	10	90
5	RDS	0.4	40	20	20	10	90
7	NewtrolTM	0.8	40	20	18	10	88
6	Biotrol	0.8	40	20	16	10	86
12	Powdered Soiltac®	1.2	45	20	10	10	85
11	Soiltac®	0.8	45	20	10	10	85
2	TerraLOC® 16	0.8	40	20	10	10	80
3	TerraLOC® HLZ	0.3	15	5	2	5	27
1	Untreated	N/A	0	0	0	0	0

The soft-crust palliatives had the higher weighted palliative ratings, mostly because they are less risky for FOD-related damage in addition to their dust abatement abilities. These products include the first five ranked products, EK35B, Dustaway®, Durasoil®, EDC™, and RDS. These products were sometimes rated lower by the pilots because of the unexpected soft landing surface they generated. Comments by pilots were that the surfaces were extremely soft, sometimes spongy, and that the skids would sink into the surface. The hard-crust palliatives often worked well at first, but after the surface began to break up, the FOD potential would increase rapidly, causing danger to the aircraft. Hard-crust palliatives include powdered Soiltac®, TerraLOC® 16, Soiltac, and TerraLOC® HLZ. Newtrol™ and Biotrol actually had crusts that were semi-hard. The soil was bound together with the palliatives, but the crust disintegrated easily, causing very low FOD potential.

Comparison of laboratory and field testing

The laboratory and field data are presented together in the following graphs for comparison purposes. The laboratory tests were completed prior to the field tests so that the performance of the palliatives could be predicted.

Penetration depth

The penetration depth is crucial for predicting the FOD potential for the brittle-crust palliatives. The average penetration data for both the laboratory and field applications can be found in Figure 30. The penetration depths for the palliatives that form a brittle hard crust are similar in the lab and in the field. These palliatives include TerraLOC® 16, TerraLOC® HLZ, powdered Soiltac®, and Soiltac®. Except for Soiltac® at 1.2 gsy, the field and laboratory crusts varied by only 0.11 in. The Soiltac® at 1.2 gsy varied slightly more, by 0.34 in., probably because the palliative was thick and did not penetrate immediately into the laboratory specimen but overflowed off the surface. EDC™ also had a similar crust in the field and the lab, varying by only 0.08 in. The remaining palliatives, RDS, Biotrol, Newtrol™, EK35B, Dustaway®, and Durasoil®, all had crusts that were actually thicker in the field than in the laboratory. The average increase for these palliatives was 0.37 in. The laboratory tests, although conservative, can be a useful tool in predicting penetration depth.

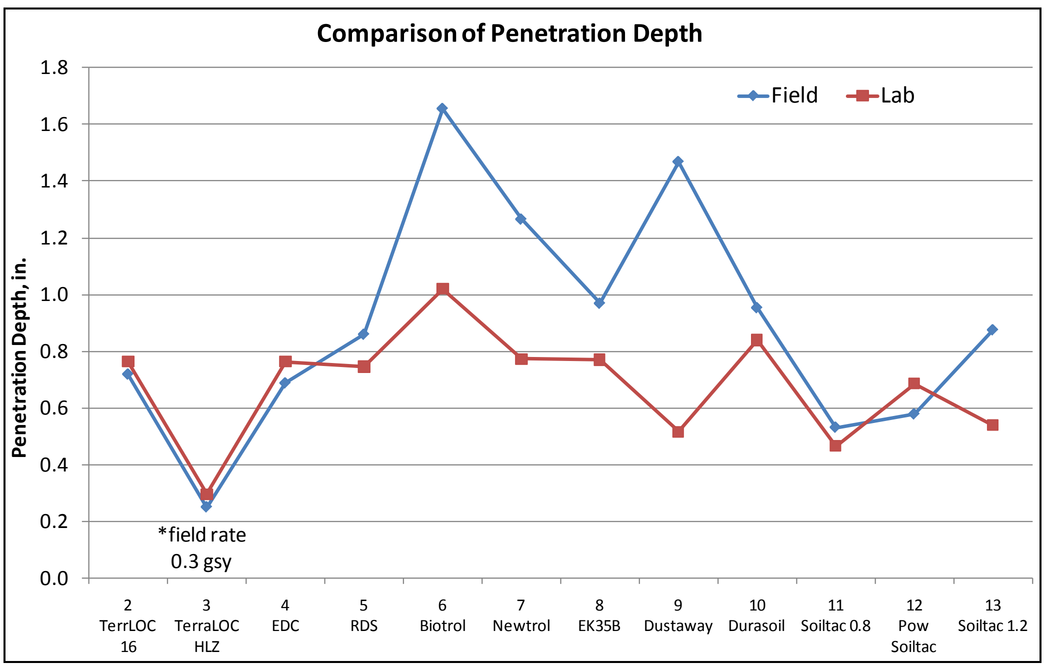


Figure 30. Comparison of penetration depth for laboratory and field tests.

Quantitative performance tests

Performance for the laboratory testing was quantified with the laboratory erosion data. Performance for the field testing was quantified with the amount of dust collected on the filters. The results of the laboratory and the field testing were compared to evaluate the efficacy of the laboratory testing in predicting field performance. In Figure 31, the average amount of dust collected on the filters during the field evaluation of all three aircraft is plotted on the same chart as the erosion data collected in the laboratory, and in Figure 32, the same data are plotted with the laboratory optical concentration data. The plotted laboratory data are the average of the three specimens tested at the same application rate as the one used in the field, except for TerraLOC® HLZ, which was applied in the field at a rate of 0.3 gsy. The lowest laboratory application rate was 0.4 gsy. Most of the palliatives tested during both field and laboratory evaluations were adequate for dust abatement on expedient helipads and received high overall weighted palliative ratings. The exception was TerraLOC® HLZ. As shown in Figure 31, the laboratory erosion data show a peak for TerraLOC® HLZ. This product was actually tested at a higher concentration in the laboratory than what was applied in the field. At the lower field-applied concentration, the lab results would probably have been even higher. The crust was too thin in both cases, measuring at an average of 0.25 in. and 0.3 in. for the field and laboratory, respectively, to prevent FOD generation. To use this product in the field, a higher application concentration or less viscous product could be beneficial.

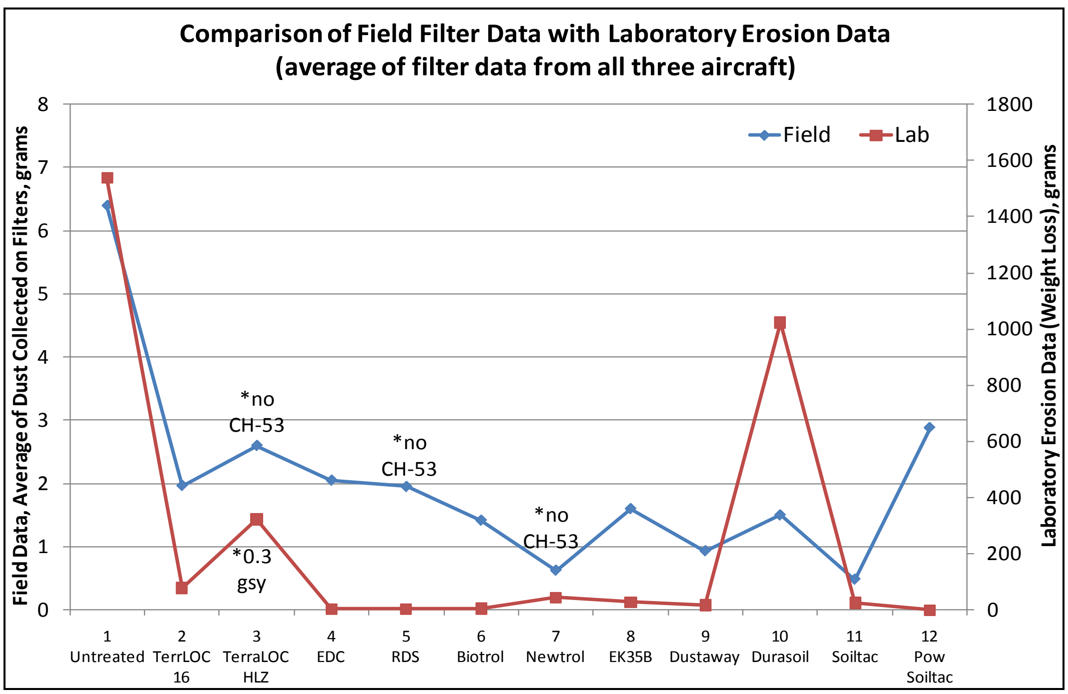


Figure 31. Comparison of field filter data with the laboratory erosion data.

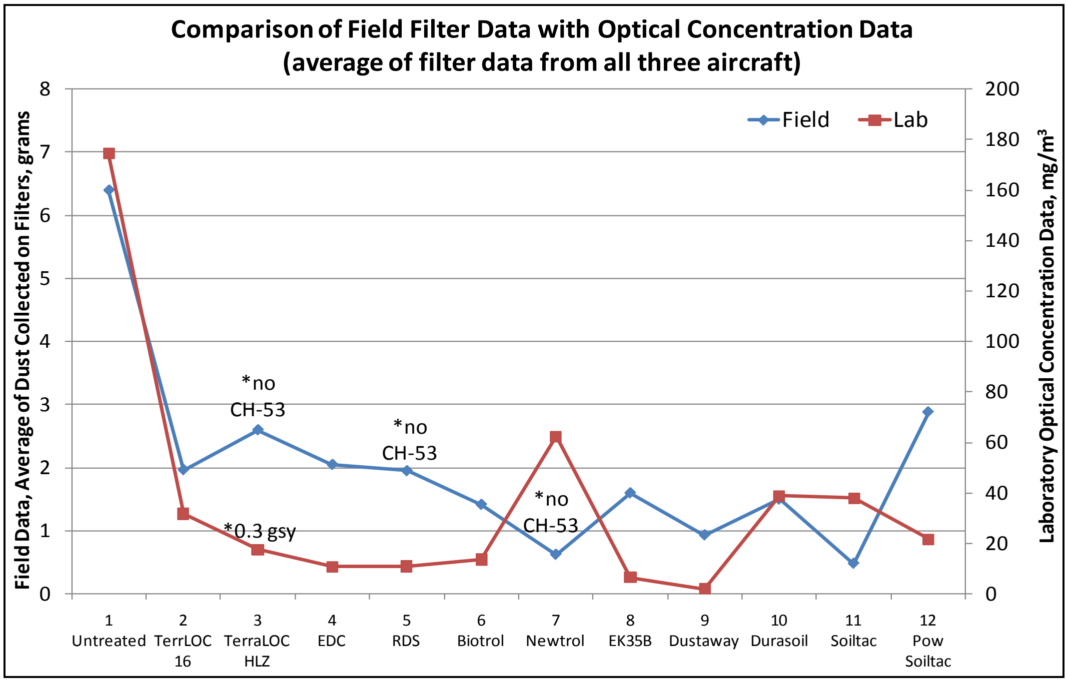


Figure 32. Comparison of field filter data with the optical concentration data.

When the laboratory erosion data are compared to the field data, as shown in Figure 31, the results are similar, except for Durasoil®. In the field, Durasoil® performed well, with a weighted palliative rating of 95. However, the laboratory erosion testing did not reflect the same behavior. As stated previously, one possibility could be the length of curing time in the laboratory (24 hr) was not long enough. However, upon inspection of the laboratory optical concentration data, Durasoil® does not follow this same trend. The optical concentration value is not dramatically different from that of the other products. Therefore, it is apparent that, to use the laboratory tests to predict the field performance, both the erosion and optical concentration data should be taken into consideration.

For Newtrol™, the optical concentration value was higher than that of the rest of the palliatives. However, the weight loss in the erosion data was low. Newtrol™ had a good field-weighted palliative rating of 88, which demonstrates another example of using both tests to evaluate the field potential for the product.

Recommendations for future tests

Based on the limited data shown here, threshold values for the laboratory testing can be recommended. If the results of future laboratory testing yield values that exceed the threshold, it could mean the product is potentially hazardous to safe operations. For the erosion data, the recommended threshold is 200 grams. For the optical concentration data, the recommended threshold is 50 mg/m^3. Another factor to consider would be the penetration depth; a thicker crust normally yields better dust abatement. All three factors evaluated during the air impingement testing (erosion/weight loss, optical concentration, and penetration depth) should be evaluated prior to field use.

5 Conclusions and Recommendations

ERDC personnel performed laboratory and field testing of new commercially available dust palliatives, as tasked by the MCSC. Laboratory tests were conducted on the palliatives to verify the required application concentration in the field. A field test was also conducted to evaluate the products under live flight testing. Aircraft used were CH-46, UH-1, and CH-53. Dust collectors and pilot feedback were used to evaluate the products.

Conclusions

The following conclusions were derived from the laboratory and field testing of selected dust palliatives:

1. The air impingement laboratory testing can be used to predict the field performance of palliatives at varied application rates. Three factors should be considered for palliatives: erosion/weight loss, optical concentration, and penetration depth. These tests can be used to estimate the minimum field application rate.
2. Crust depths for specific application rates can be predicted based on the laboratory application results. The prediction may be conservative, meaning that the crusts are thicker in the field.
3. Laboratory tests can predict performance of the dust palliatives. Both the erosion and optical concentration data should be taken into consideration when reviewing a palliative. Penetration depth is also another factor to consider.
4. Upon reviewing the data from this evaluation, the following threshold values are recommended for the prediction of field performance from laboratory testing: weight loss of 200 grams from the erosion data and HazDust reading of 50 mg/m^3 for the optical concentration data. These threshold values should be used for guidance only; actual field performance could vary.
5. The following products are suitable for dust abatement on expedient helipads when applied in the same manner as the procedure used during the field testing: TerraLOC® 16, EDC™, RDS, Biotrol, Newtrol™, EK35B, Dustaway®, Durasoil®, Soiltac®, and powdered Soiltac®.
6. Oil-based products forming a soft crust were effective at the lower application concentration of 0.4 gsy. Laboratory testing indicates that a

higher concentration for these products is not beneficial. These products include EDC™, RDS, and EK35B.

7. Brittle-crust-forming products were also effective for dust abatement; however, care should be taken to ensure that at least a 1-in. crust is created prior to use to prevent FOD generation. These products include TerraLOC® 16, Soiltac®, and powdered Soiltac®.
8. Products that formed a semi-hard crust were also effective for dust abatement. Weighted palliative ratings for these products were higher than those for the brittle-crust products because these are less likely to cause FOD-related damage. These products include Newtrol™ and Biotrol.
9. TerraLOC® HLZ was the least effective palliative tested during the field testing. It was extremely thick, difficult to apply, and did not provide consistent coverage. It is recommended that the product be diluted and that the application rate be increased.
10. The soft-crust palliatives form a surface that pilots are not accustomed to landing on; this may account for some of the variability between dust collection data and pilot evaluation.
11. Gravity buckets are not a valid method of quantifying dust abatement. Too much variability was measured during the field testing with the gravity buckets.

Recommendations

Based on the laboratory and field testing, the following recommendations are provided:

1. While most of the products tested during this exercise were found to be effective, the ability of the products to recover was not examined during this test. Future testing of the palliative recovery after landings would be beneficial. Most products recommend simple reapplication, but others, such as TerraLOC®, recommend using only water to reactivate the palliative.
2. Laboratory testing is recommended for newly developed palliatives prior to their usage in the field. A further recommendation is that future palliatives undergo the same testing as described in this report to create a better database of products as well as to determine the most effective application rate and efficacy of the product.

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Appendix A: Laboratory Testing Photographs

Photographs from the flight testing evaluation are included in this appendix.

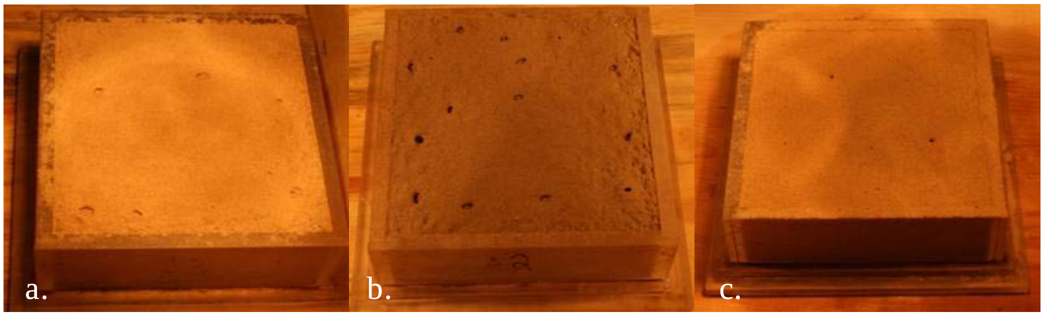

Figure A1. Specimens treated with water at application rates of 0.4 gsy (A), 0.8 gsy (B), and 1.2 gsy (C). These specimens were considered untreated and used as the control.

Figure A2. Specimens treated with water, after air impingement testing. Application rate for the top row was 0.4 gsy; middle row, 0.8 gsy; and bottom row, 1.2 gsy. No crust remained after the air impingement testing.

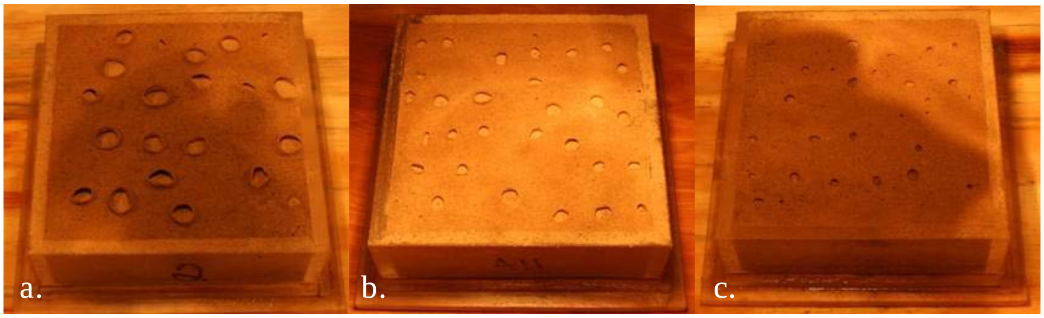

Figure A3. Specimens treated with TerraLOC® 16 at application rates of 0.4 gsy (A), 0.8 gsy (B), and 1.2 gsy (C).

Figure A4. Specimens treated with TerraLOC® 16 after air impingement testing. Application rate for the top row was 0.4 gsy; middle row, 0.8 gsy; and bottom row, 1.2 gsy.

Figure A5. Specimens treated with TerraLOC® 16 after penetration depths were measured. The crust was hard and brittle; sand in the cavities blew away easily.

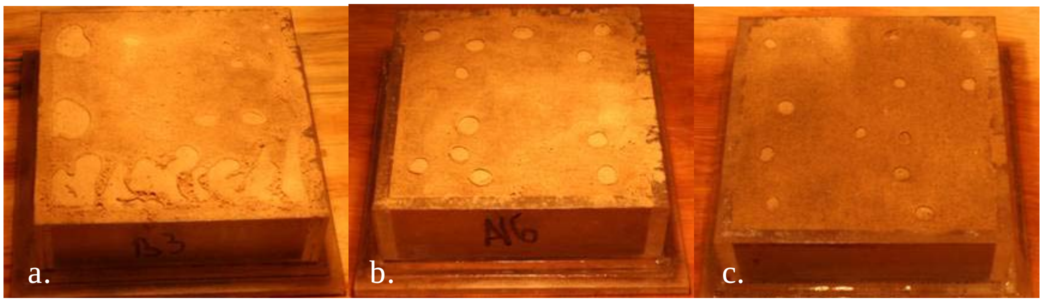

Figure A6. Specimens treated with TerraLOC® HLZ with a concentration of 0.4 gsy (A), 0.8 gsy (B), and 1.2 gsy (C).

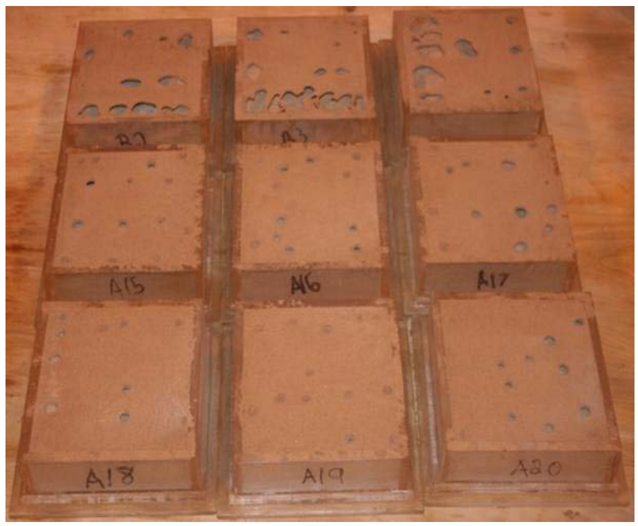

Figure A7. Specimens treated with TerraLOC® HLZ after air impingement testing. Application rate for the top row was 0.4 gsy; middle row, 0.8 gsy; and bottom row, 1.2 gsy.

Figure A8. Specimens treated with TerraLOC® HLZ after penetration depths were measured.

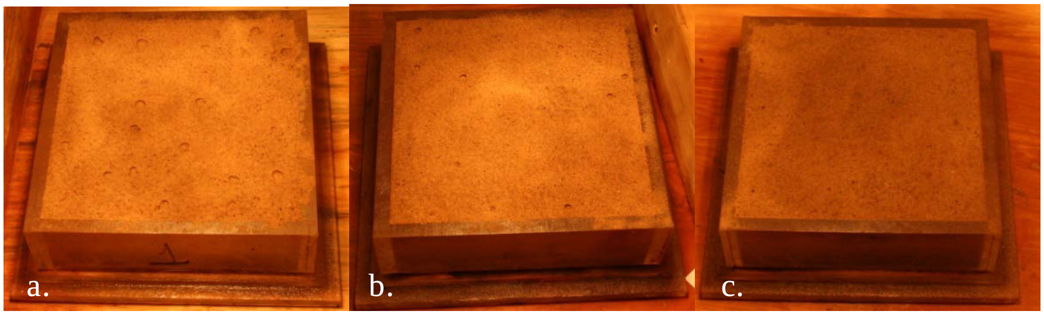

Figure A9. Specimens treated with EDC™ at application rates of 0.4 gsy (A), 0.8 gsy (B), and 1.2 gsy (C).


Figure A10. Specimens treated with EDC™, after air impingement testing. Application rate for the top row was 0.4 gsy, middle row was 0.8 gsy, and bottom row was 1.2 gsy.

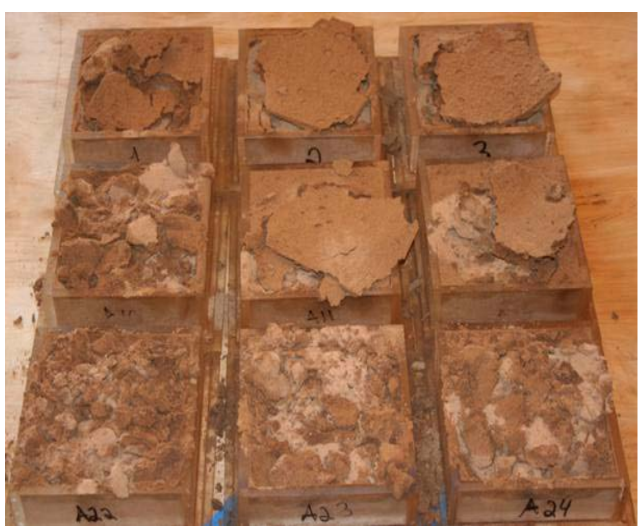
Figure A11. Specimens treated with EDC™ after penetration depths were measured.

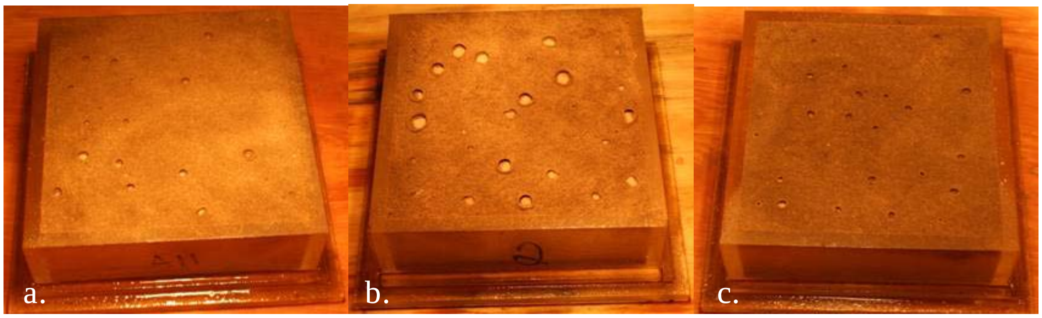

Figure A12. Specimens treated with RDS at application rates of 0.4 gsy (A), 0.8 gsy (B), and 1.2 gsy (C).

Figure A13. Specimens treated with RDS, after air impingement testing. Application rate for the top row was 0.4 gsy, middle row was 0.8 gsy, and bottom row was 1.2 gsy.

Figure A14. Specimens treated with RDS after penetration depths were measured.

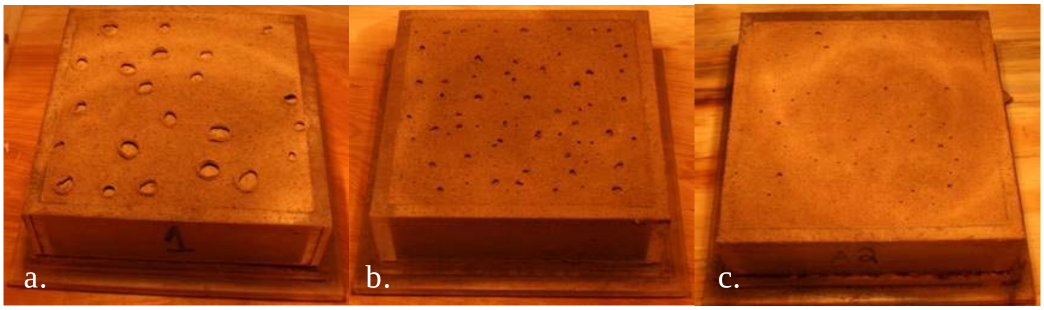

Figure A15. Specimens treated with Biotrol at application rates of 0.4 gsy (A), 0.8 gsy (B), and 1.2 gsy (C).

Figure A16. Specimens treated with Biotrol after air impingement testing. Application rate for the top row was 0.4 gsy, middle row was 0.8 gsy, and bottom row was 1.2 gsy.

Figure A17. Specimens treated with Biotrol after penetration depths were measured.

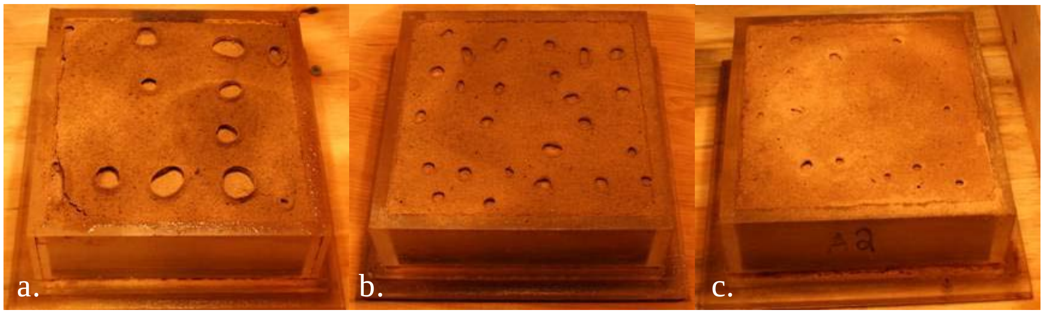

Figure A18. Specimens treated with Newtrol™ at application rates of 0.4 gsy (A), 0.8 gsy (B), and 1.2 gsy (C).

Figure A19. Specimens treated with Newtrol™, after air impingement testing. Application rate for the top row was 0.4 gsy, middle row was 0.8 gsy, and bottom row was 1.2 gsy.

Figure A20. Specimens treated with Newtrol™ after penetration depths were measured.

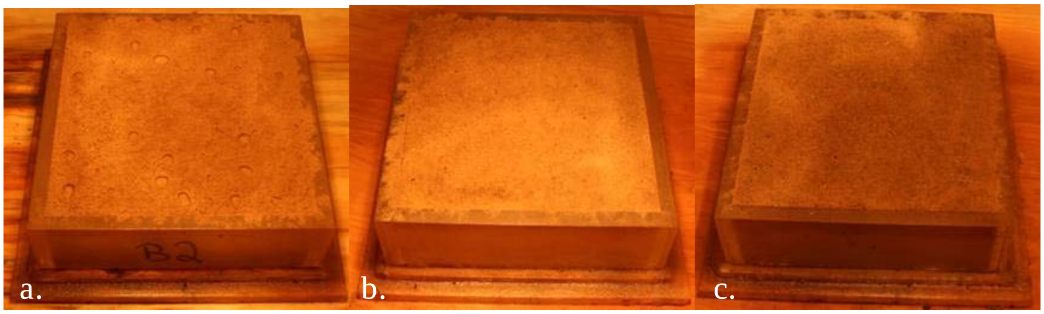

Figure A21. Specimens treated with EK35B at application rates of 0.4 gsy (A), 0.8 gsy (B), and 1.2 gsy (C).

Figure A22. Specimens treated with EK35B after air impingement testing. Application rate for the top row was 0.4 gsy, middle row was 0.8 gsy, and bottom row was 1.2 gsy.

Figure A23. Specimens treated with EK35B after penetration depths were measured.

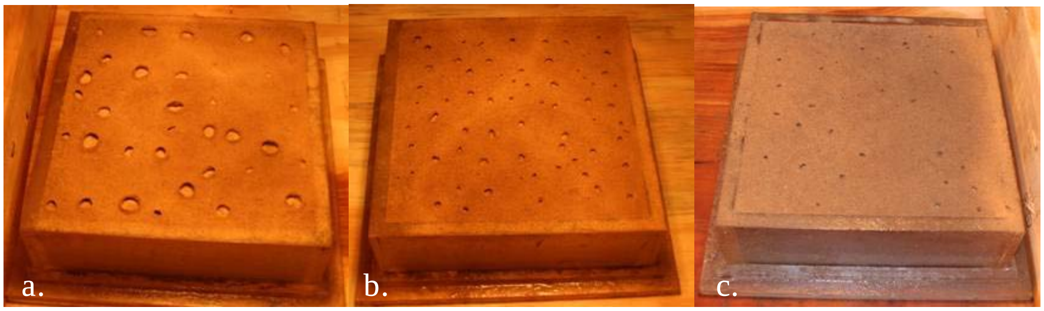

Figure A24. Specimens treated with Dustaway® at application rates of 0.4 gsy (A), 0.8 gsy (B), and 1.2 gsy (C).

Figure A25. Specimens treated with Dustaway® after air impingement testing. Application rate for the top row was 0.4 gsy, middle row was 0.8 gsy, and bottom row was 1.2 gsy.

Figure A26. Specimens treated with Dustaway® after penetration depths were measured.

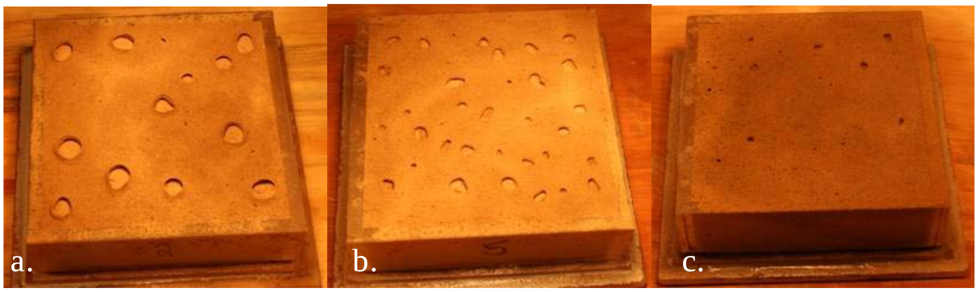

Figure A27. Specimens treated with powdered Soiltac® at application rates of 0.4 gsy (A), 0.8 gsy (B), and 1.2 gsy (C).

Figure A28. Specimens treated with powdered Soiltac® after air impingement testing. Application rate for the top row was 0.4 gsy, middle row was 0.8 gsy, and bottom row was 1.2 gsy.

Figure A29. Specimens treated with powdered Soiltac® after penetration depths were measured.

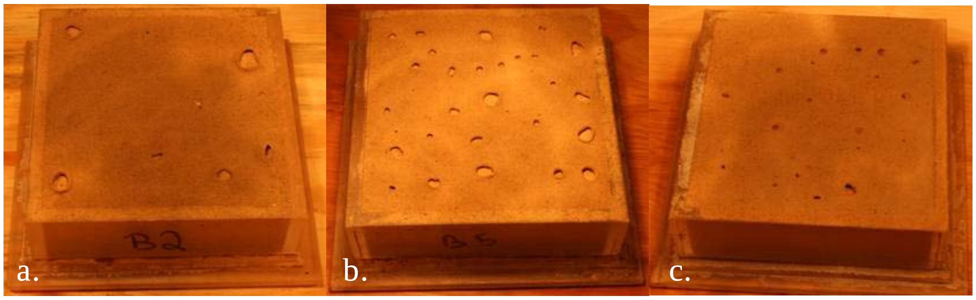

Figure A30. Specimens treated with liquid Soiltac® at application rates of 0.4 gsy (A), 0.8 gsy (B), and 1.2 gsy (C).

Figure A31. Specimens treated with liquid Soiltac® after air impingement testing. Application rate for the top row was 0.4 gsy, middle row was 0.8 gsy, and bottom row was 1.2 gsy.

Figure A32. Specimens treated with liquid Soiltac® after penetration depths were measured.

Appendix B: Flight Testing Photographs

Photographs from the flight testing evaluation are included in this appendix.

Figure B1. CH-46 landing on helipad 1 (untreated).

Figure B2. CH-46 landing on helipad 2 (TerraLOC® 16, 0.8 gsy).

Figure B3. CH-46 landing on helipad 3 (TerraLOC® HLZ, 0.3 gsy).

Figure B4. CH-46 landing on helipad 4 (EDC™, 0.4 gsy).

Figure B5. CH-46 landing on helipad 5 (RDS, 0.4 gsy).

Figure B6. CH-46 landing on helipad 6 (Biotrol, 0.8 gsy).

Figure B7. CH-46 landing on helipad 7 (Newtrol™, 0.8 gsy).

Figure B8. CH-46 landing on helipad 8 (EK35B, 0.4 gsy).

Figure B9. CH-46 landing on helipad 9 (Dustaway®, 1.2 gsy).

Figure B10. CH-46 landing on helipad 10 (Durasoil®, 0.4 gsy)

Figure B11. CH-46 landing on helipad 11 (Soiltac®, low, 0.8 gsy).

Figure B12. CH-46 landing on helipad 12 (powdered Soiltac®, 1.2 gsy).

Figure B13. UH-1 landing on helipad 1 (untreated).

Figure B14. UH-1 landing on helipad 2 (TerraLOC® 16, 0.8 gsy).

Figure B15. UH-1 landing on helipad 3 (TerraLOC® HLZ, 0.3 gsy).

Figure B16. UH-1 landing on helipad 4 (EDC™, 0.4 gsy).

Figure B17. UH-1 landing on helipad 5 (RDS, 0.4 gsy).

Figure B18. UH-1 landing on helipad 6 (Biotrol, 0.8 gsy).

Figure B19. UH-1 landing on helipad 7 (Newtrol™, 0.8 gsy).

Figure B20. UH-1 landing on helipad 8 (EK35B, 0.4 gsy).

Figure B21. UH-1 landing on helipad 9 (Dustaway®, 1.2 gsy).

Figure B22. UH-1 landing on helipad 10 (Durasoil®, 0.4 gsy).

Figure B23. UH-1 landing on helipad 11 (Soiltac®, low, 0.8 gsy).

Figure B24. UH-1 landing on helipad 12 (powdered Soiltac®, 1.2 gsy).

Figure B25. CH-53 landing on helipad 1 (untreated).

Figure B26. CH-53 landing on helipad 2 (TerraLOC® 16, 0.8 gsy).

Figure B27. CH-53 landing on helipad 4 (EDC™, 0.4 gsy).

Figure B28. CH-53 landing on helipad 6 (Biotrol, 0.8 gsy).

Figure B29. CH-53 landing on helipad 8 (EK35B, 0.4 gsy).

Figure B30. CH-53 landing on helipad 9 (Dustaway®, 1.2 gsy).

Figure B31. CH-53 landing on helipad 10 (Durasoil®, 0.4 gsy).

Figure B32. CH-53 landing on helipad 11 (Soiltac®, low, 0.8 gsy).

Figure B33. CH-53 landing on helipad 12 (powdered Soiltac®, 1.2 gsy).

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14. ABSTRACT

The ERDC was tasked by the U.S. Marine Corps Systems Command to evaluate the new commercial dust palliatives for mitigating dust on helipads developed since the comprehensive testing performed by the ERDC in 2005. Both laboratory and field evaluations were performed on the dust palliatives. Laboratory evaluation consisted of observing the erosion and optical dust concentrations behaviors for three product application concentrations, 0.4, 0.8, and 1.2 gsy (gallons/square yard). Field evaluation of the dust consisted of constructing 150 ft by 150 ft helipads at the Marine Corps Air Station, Yuma, Arizona, and evaluating the ability of the dust palliatives to prevent dust and foreign object debris and compatibility with existing USMC dust abatement equipment. Approved products will be used to update the USMC Dust Control Handbook (PCN 50011240000).

15. SUBJECT TERMS

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